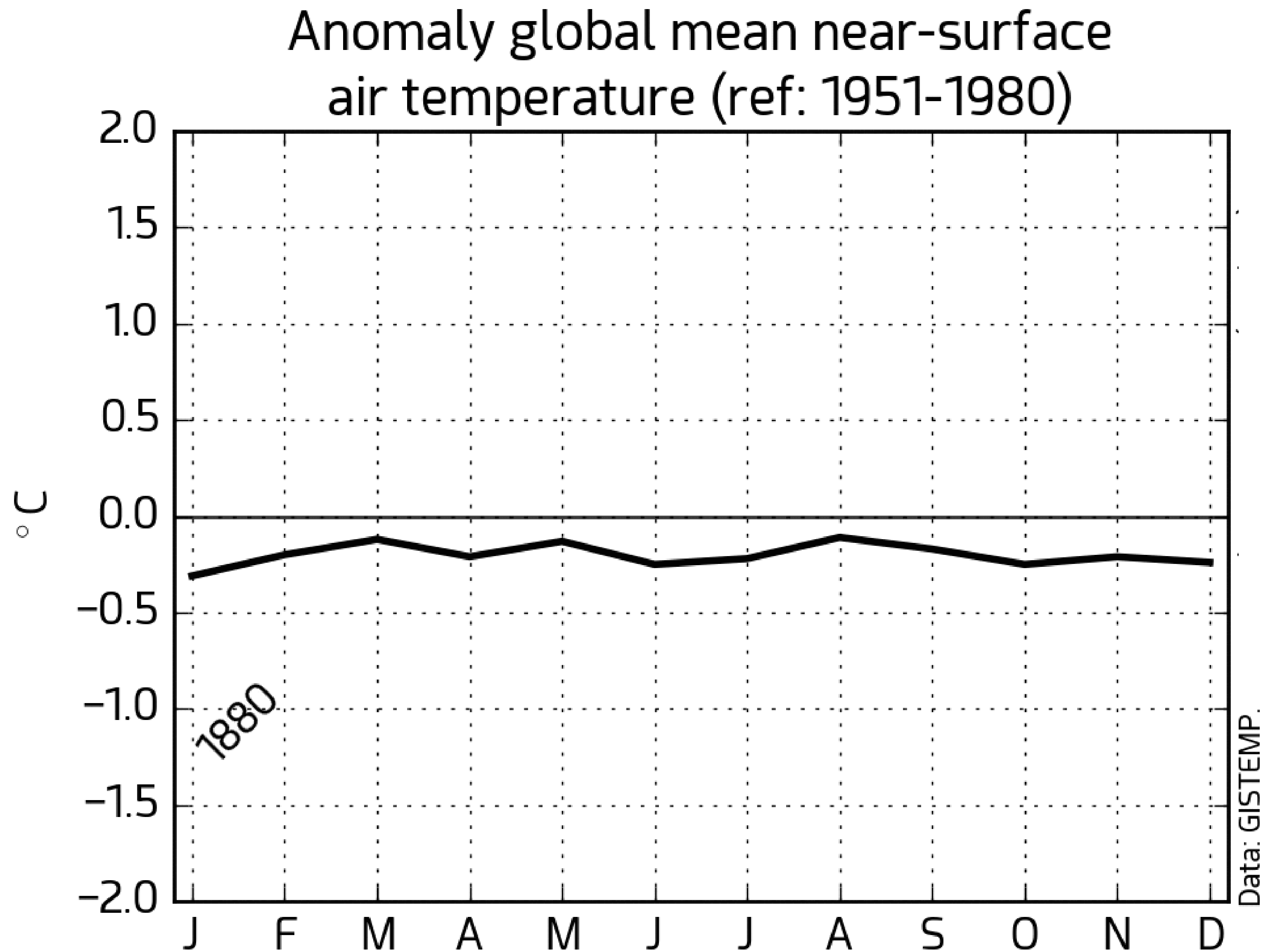
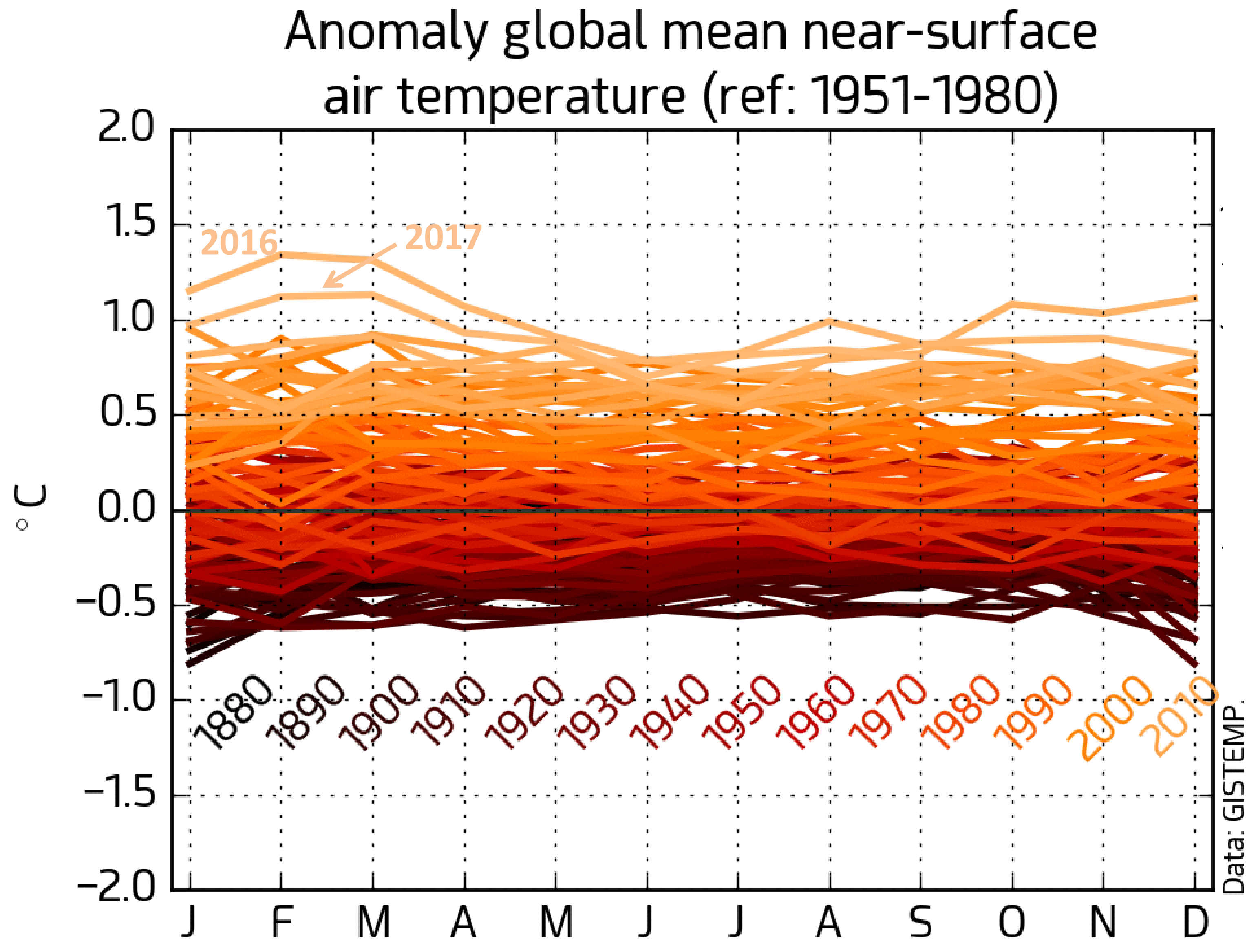
Severo Ochoa Seminar
BSC
14th November 2017

Re-interpreting thermodynamic sea-ice feedbacks

François Massonnet

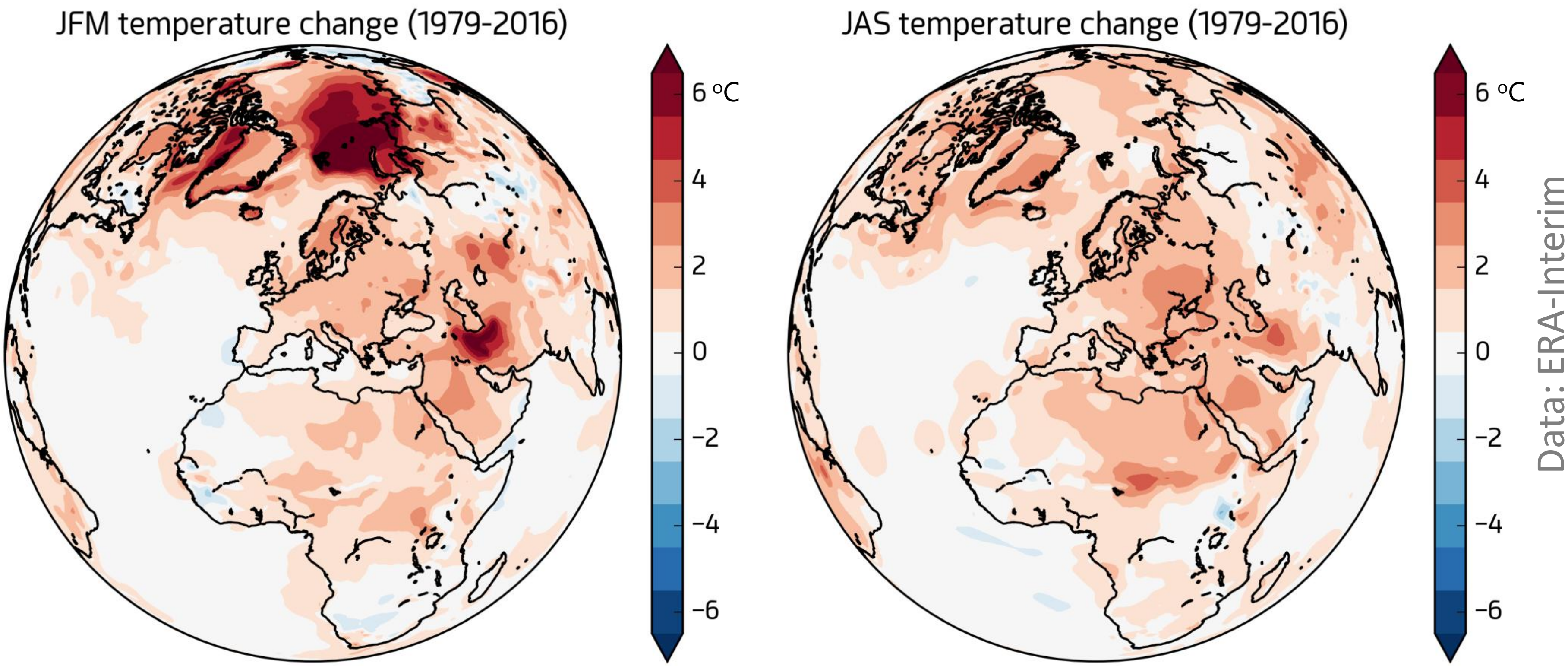
M. Vancoppenolle, H. Goosse, D. Docquier, T. Fichefet, E. Blanchard


Anomaly global mean near-surface air temperature (ref: 1951-1980)
2.0
1.5
1.0
0.5
0.0
−0.5
−1.0
−1.5
−2.0
°C
1880
J
F
M
A
M
J
J
A
S
O
N
D
Data: GISTEMP



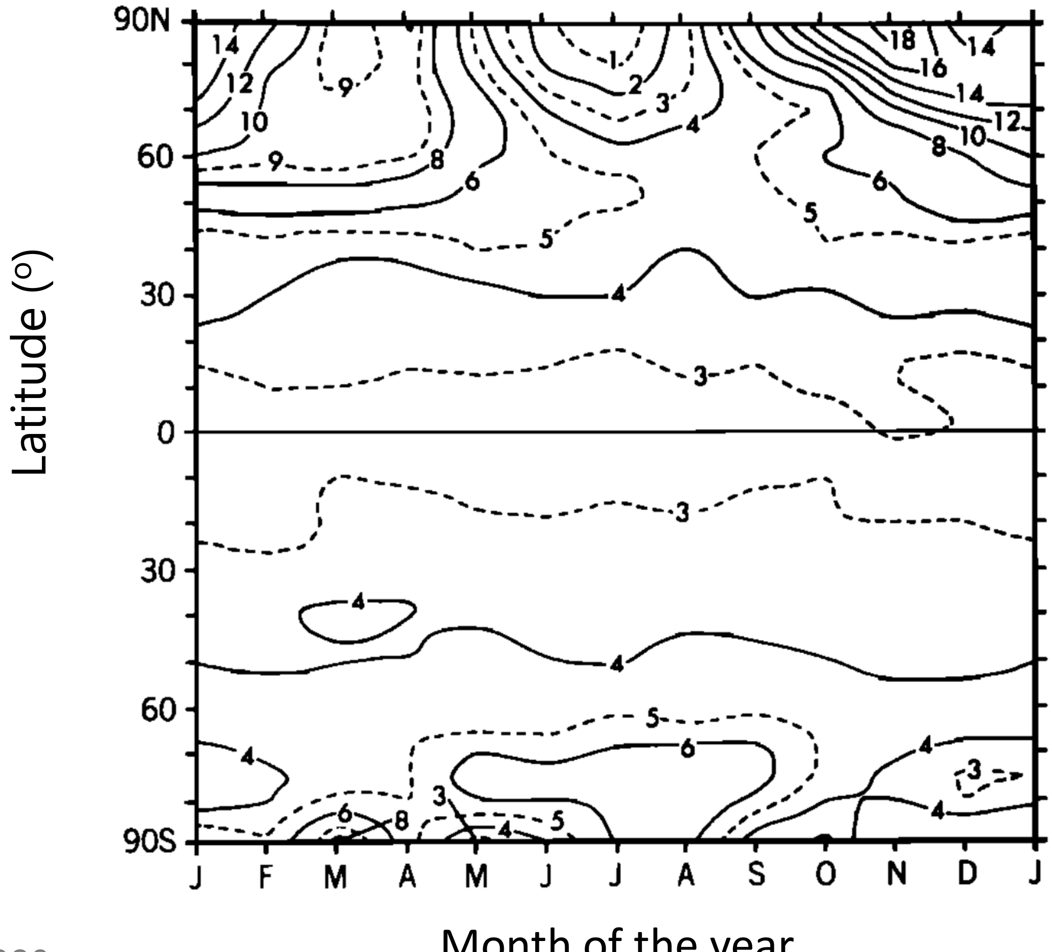
www.climate.be:3000/TECLIM/ClimateData (branch develop-fmasson)

Surface warming is amplified in the Arctic, and during winter



This had been actually predicted 40 years ago!

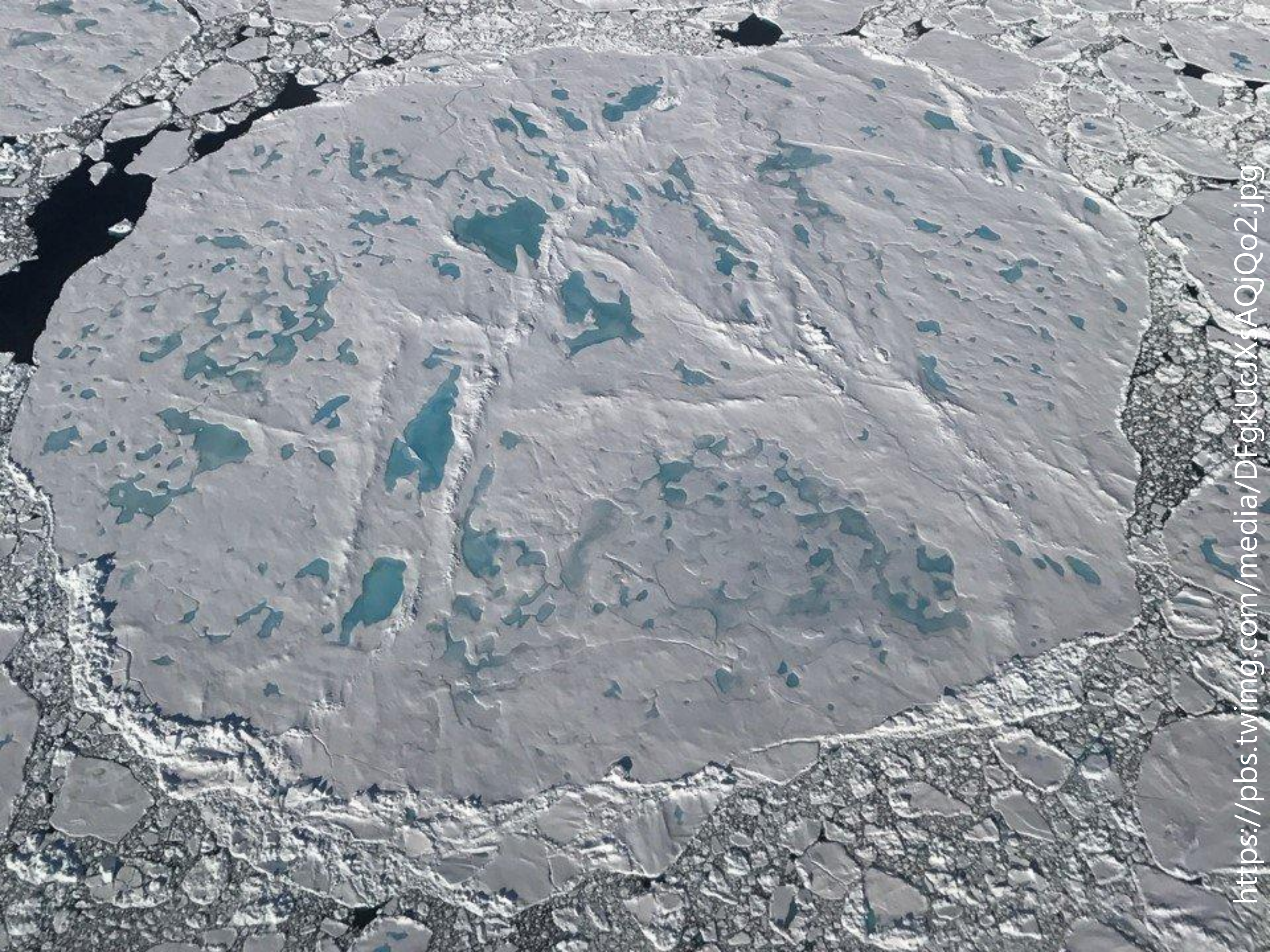
Temperature change (4 x CO_2) simulated by one of the very first climate models



Manabe and Stouffer, 1980

https://www.nasa.gov/feature/goddard/2017/nasa-scientists-seek-to-improve-sea-ice-predictions

https://pbs.twimg.com/media/DIf_CrW0AEC41U.jpg

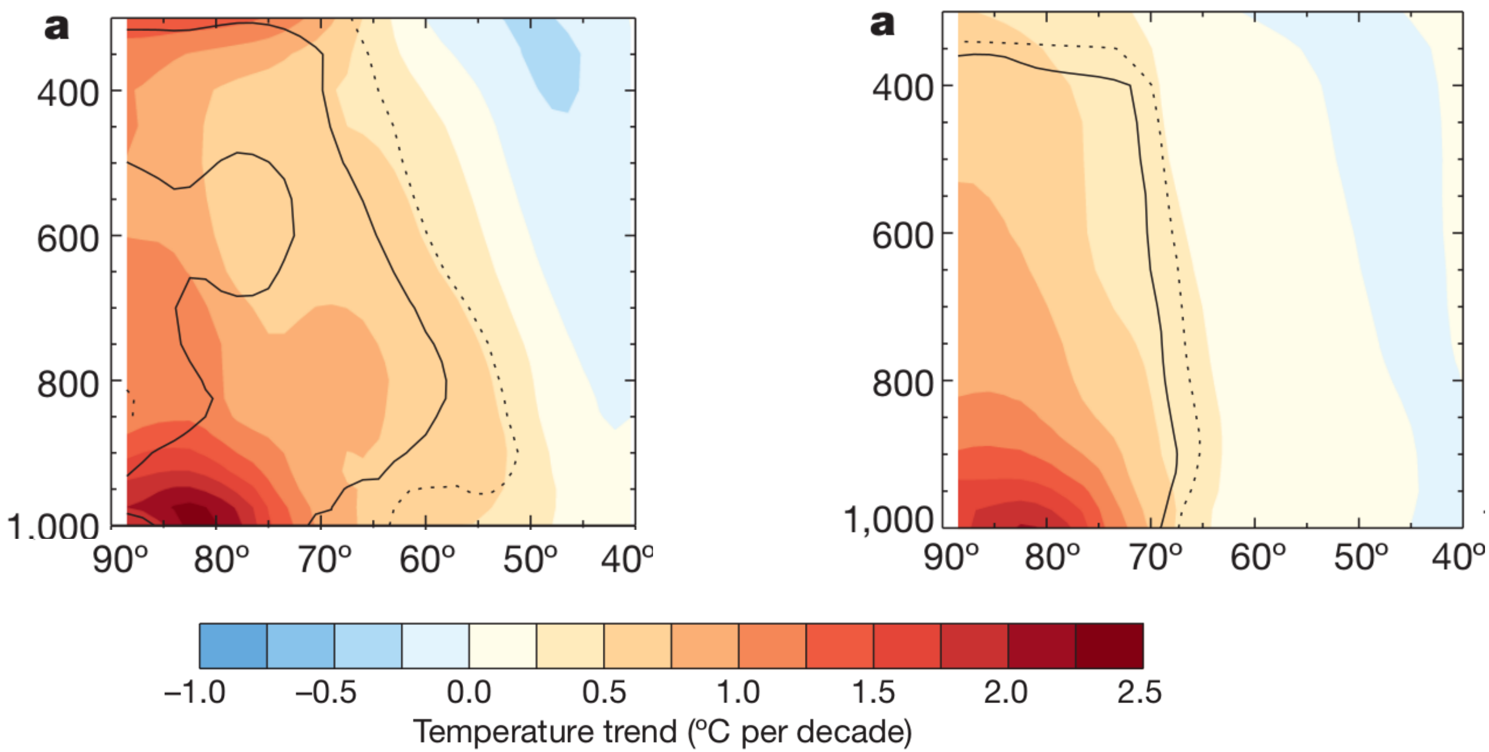


Sea ice is a main player of Arctic Amplification

Temperature trends (1989-2008)

Reconstructed temperature trends from sea ice trends (1989-2008)

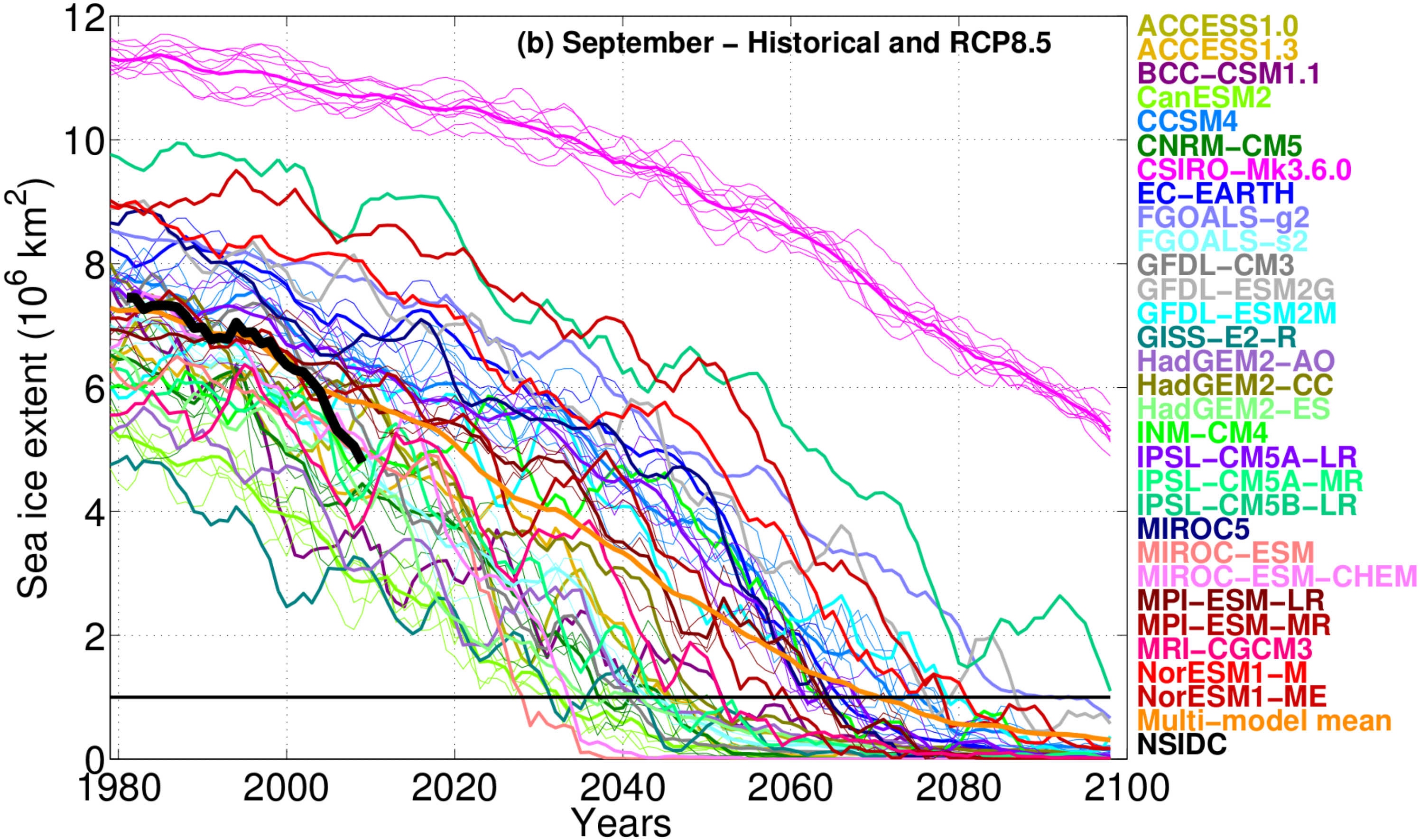
Pressure level (hPa)



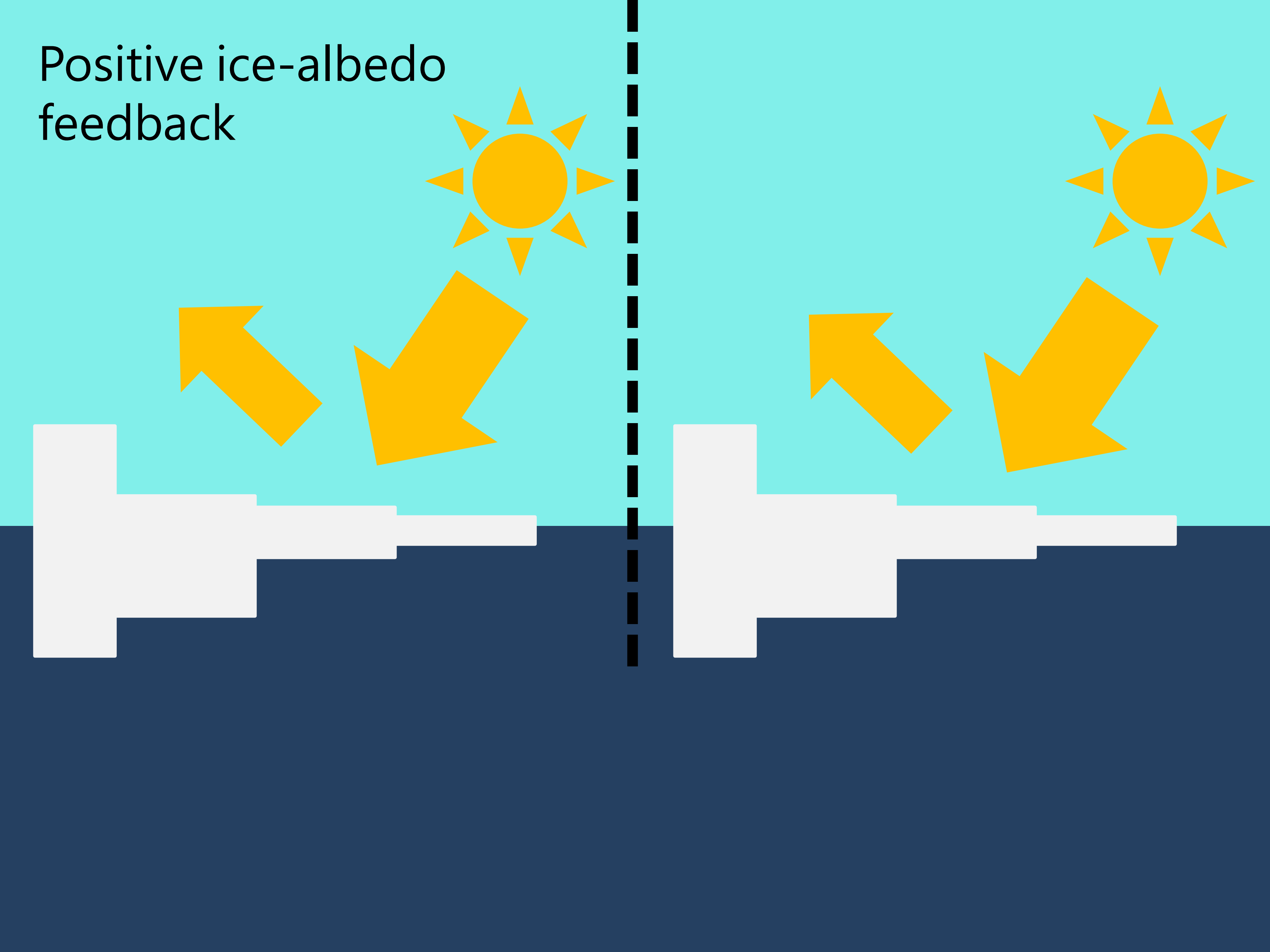
Screen and Simmonds, 2010

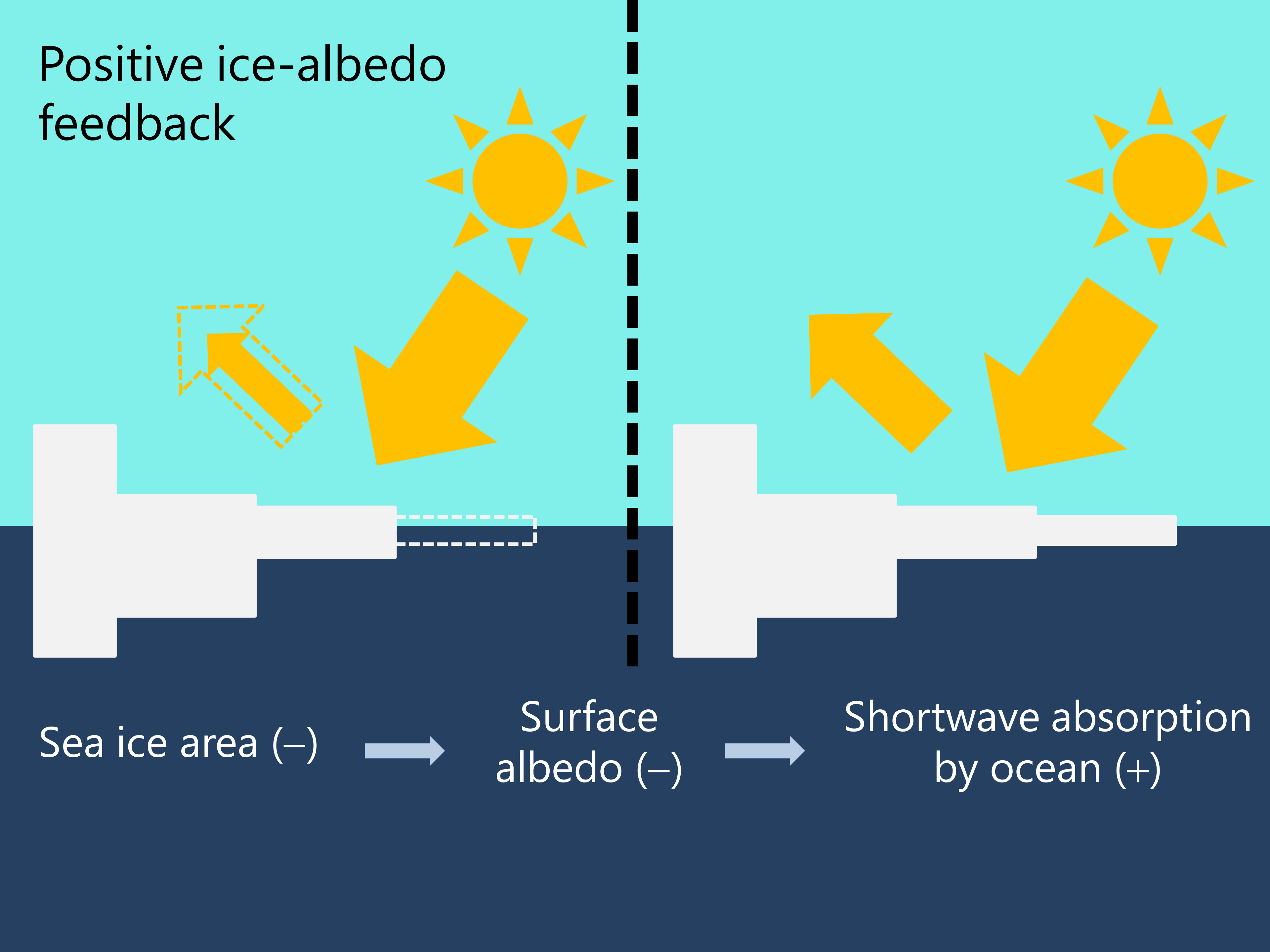
Climate models agree on the sign, but not on the magnitude of projected sea ice loss

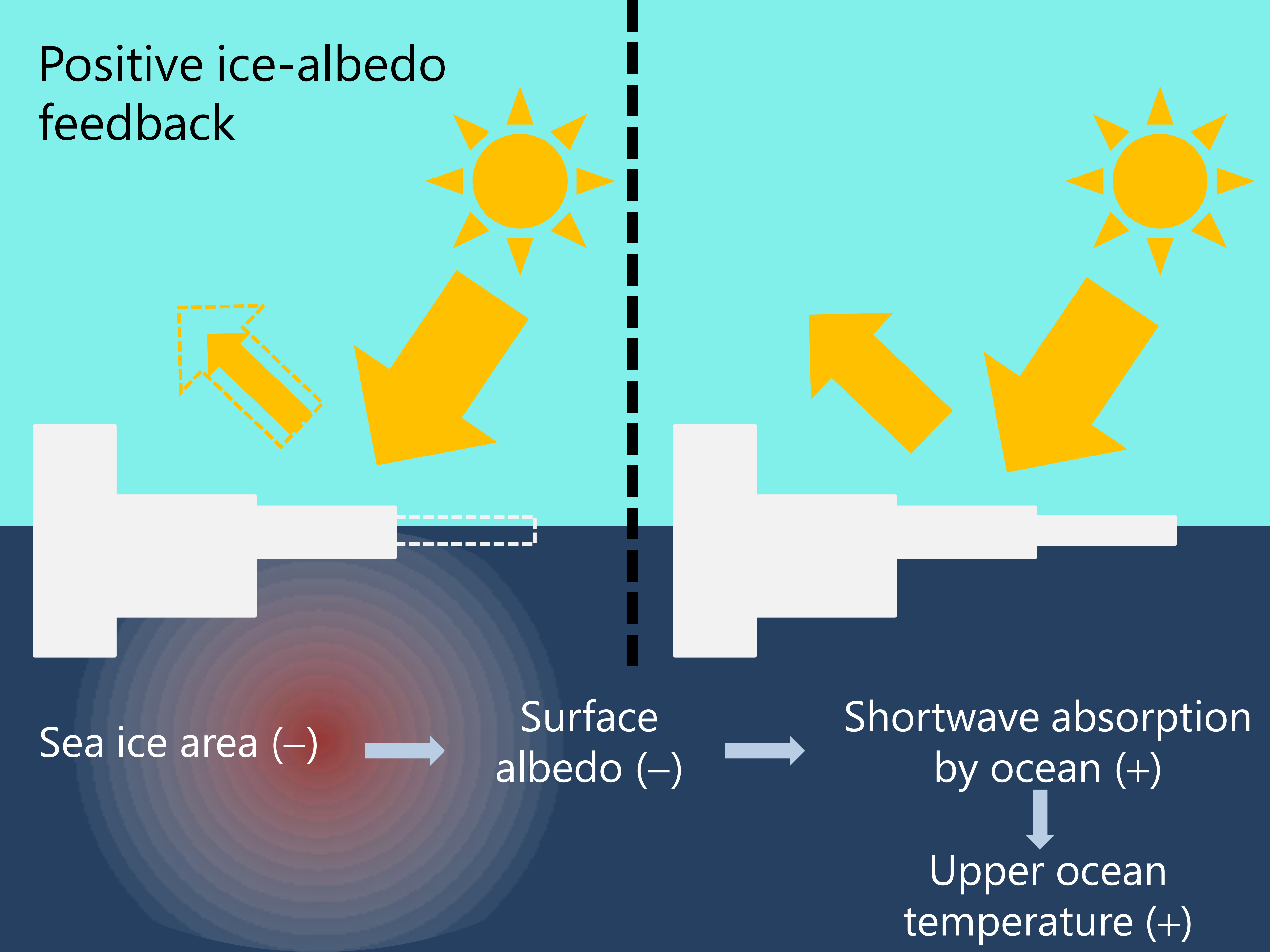
September Arctic sea ice extent (« business as usual » scenario)

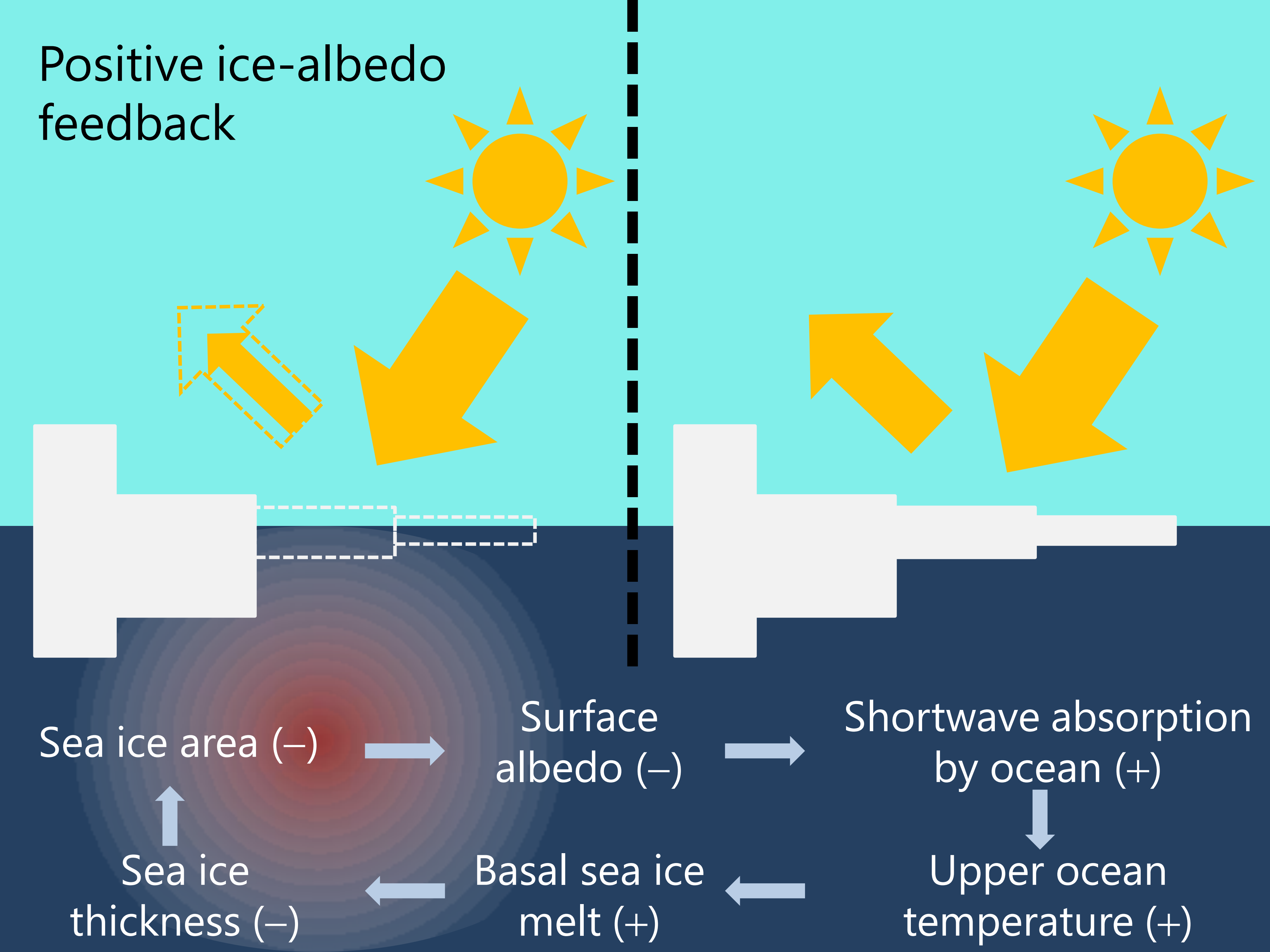


Massonnet et al., 2012

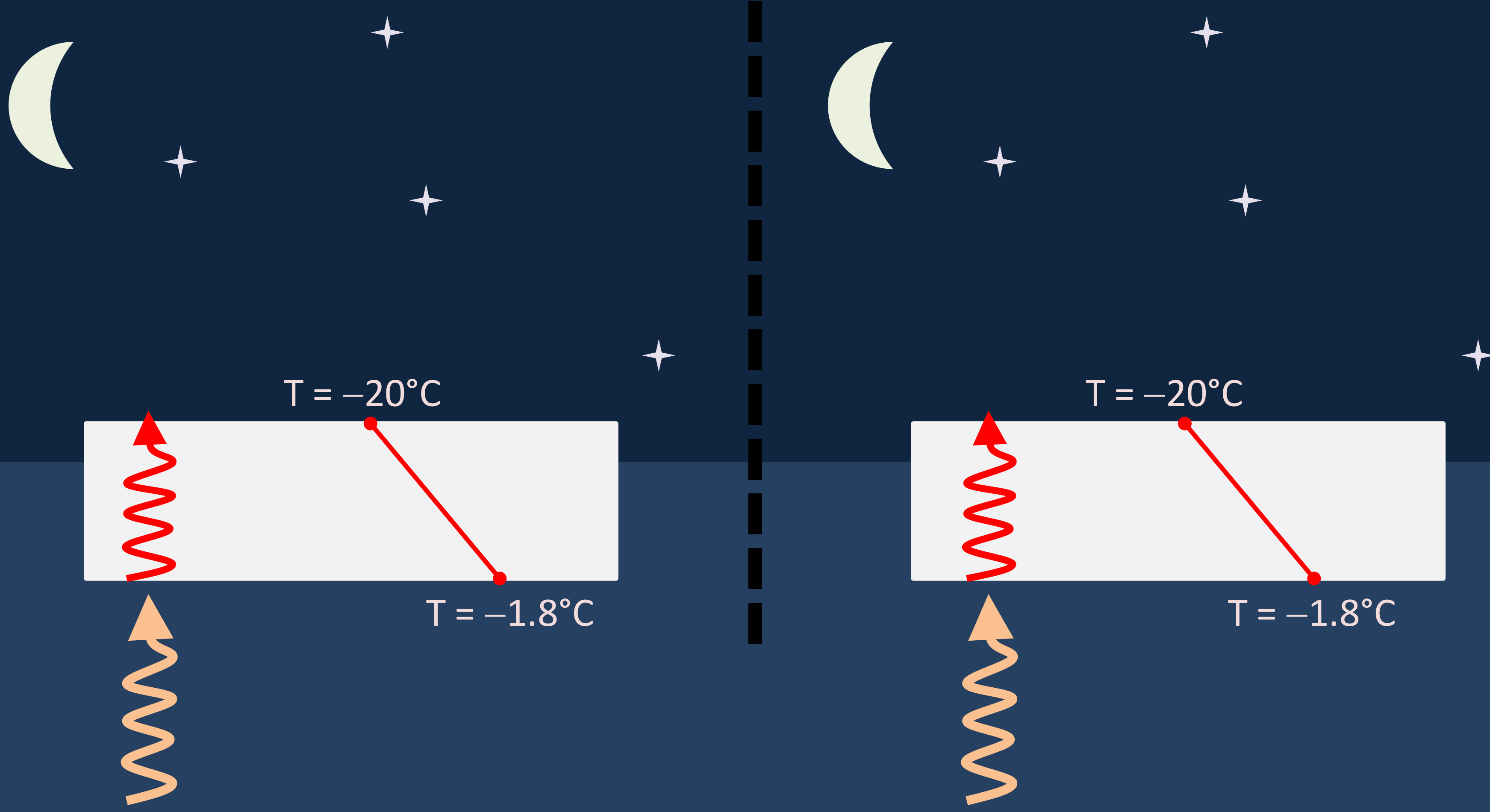

Positive ice-albedo feedback

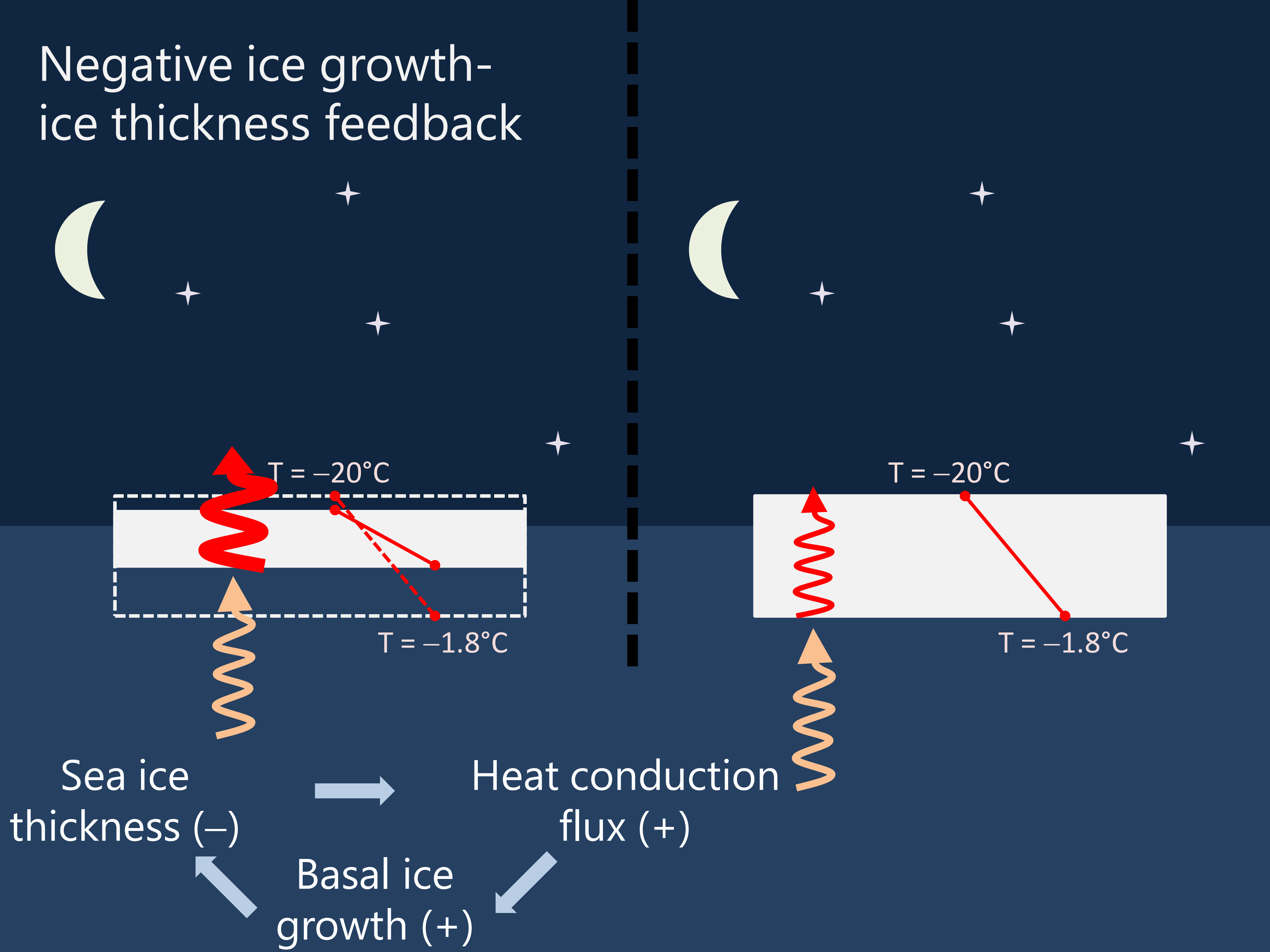

Positive ice-albedo feedback
Sea ice area (–)
Surface albedo (–)
Shortwave absorption by ocean (+)


Positive ice-albedo feedback
Sea ice area (–)
Surface albedo (–)
Shortwave absorption by ocean (+)
Upper ocean temperature (+)

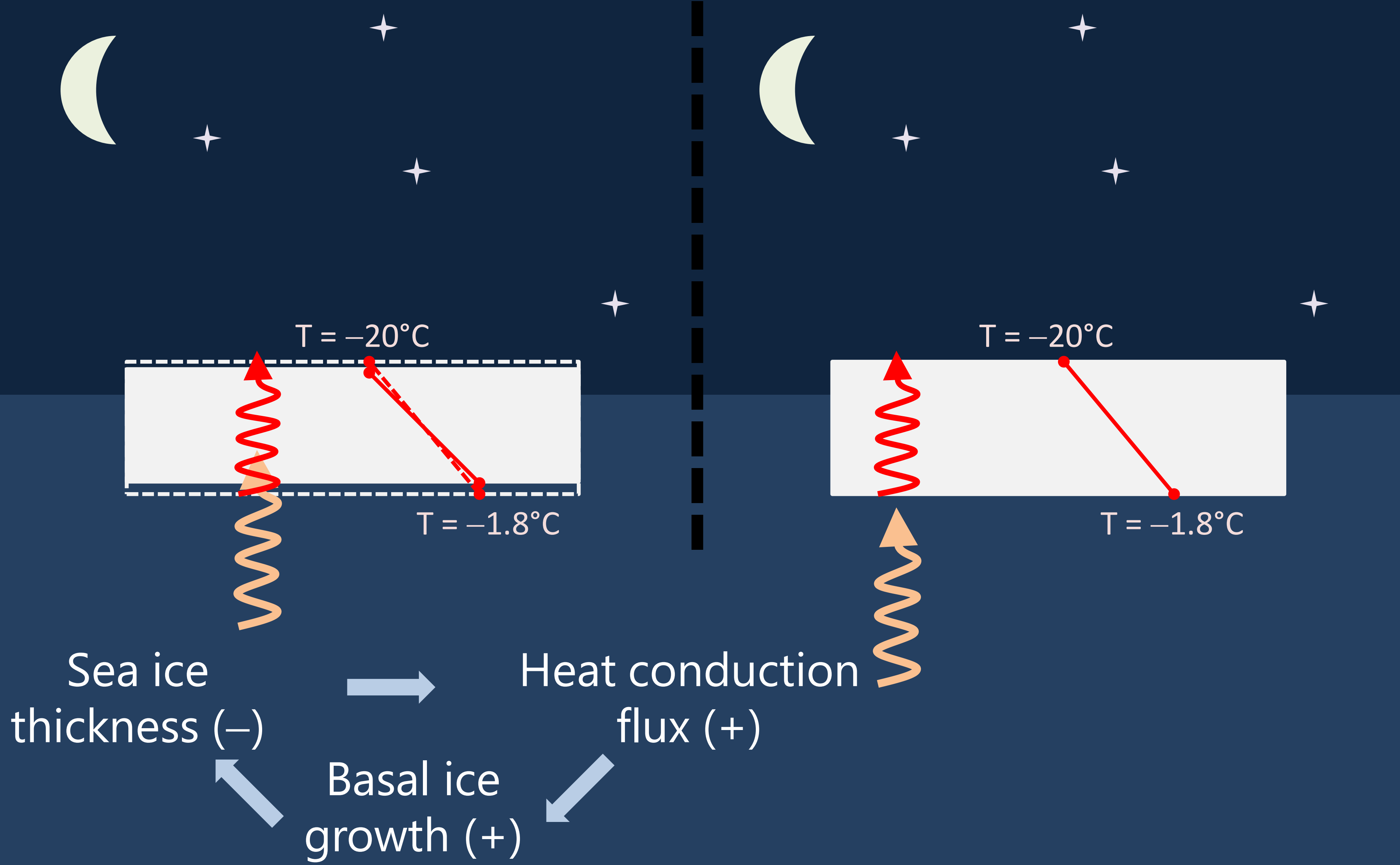

Positive ice-albedo feedback
Sea ice area (–)
Surface albedo (–)
Shortwave absorption by ocean (+)
Upper ocean temperature (+)
Basal sea ice melt (+)
Sea ice thickness (–)

Negative ice growth-ice thickness feedback

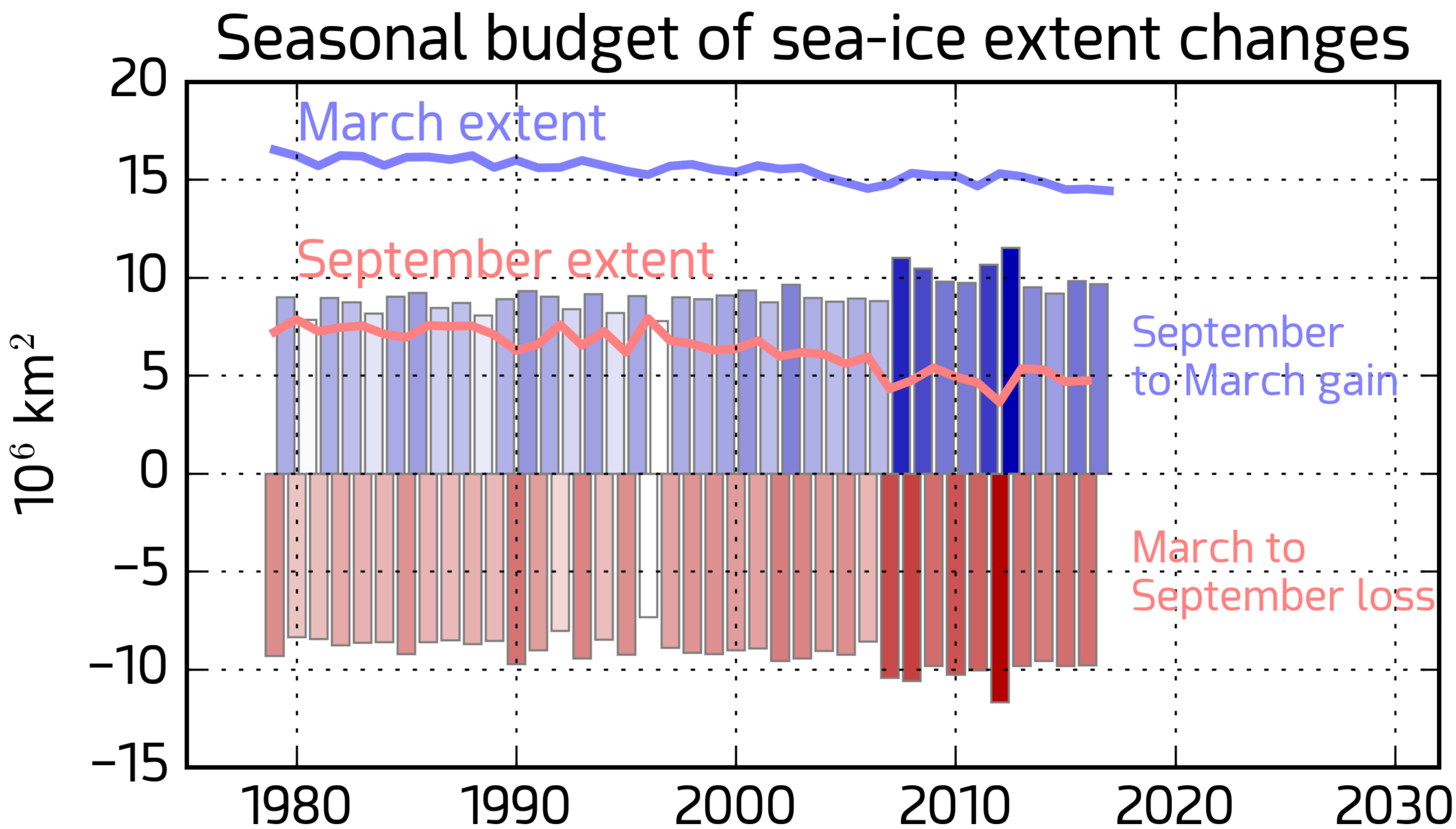



Negative ice growth-
ice thickness feedback
T = –20°C
T = –1.8°C
T = –20°C
T = –1.8°C
Sea ice
thickness (–)
Heat conduction
flux (+)
Basal ice
growth (+)

Negative ice growth-ice thickness feedback



Signature of the two feedbacks



Four scientific questions

1. Are the two feedbacks captured by contemporary climate models?

2. Do they simulate the feedbacks differently? Why?

3. What is the link between the feedbacks and sea ice variability?

4. Does it matter for seasonal to decadal prediction?

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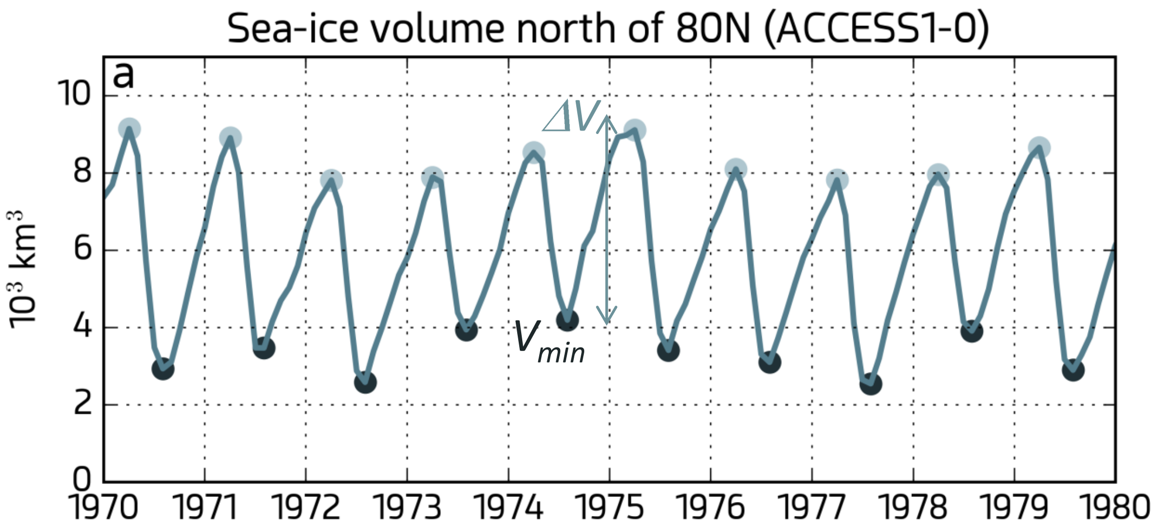
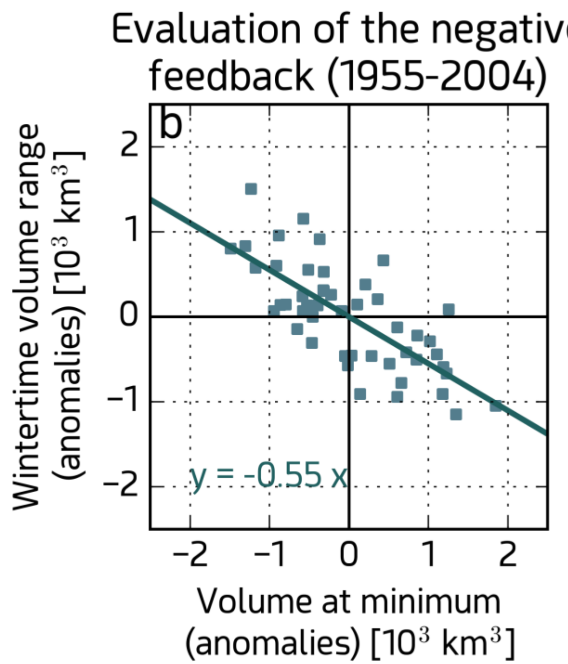
Estimating the negative feedback from model output





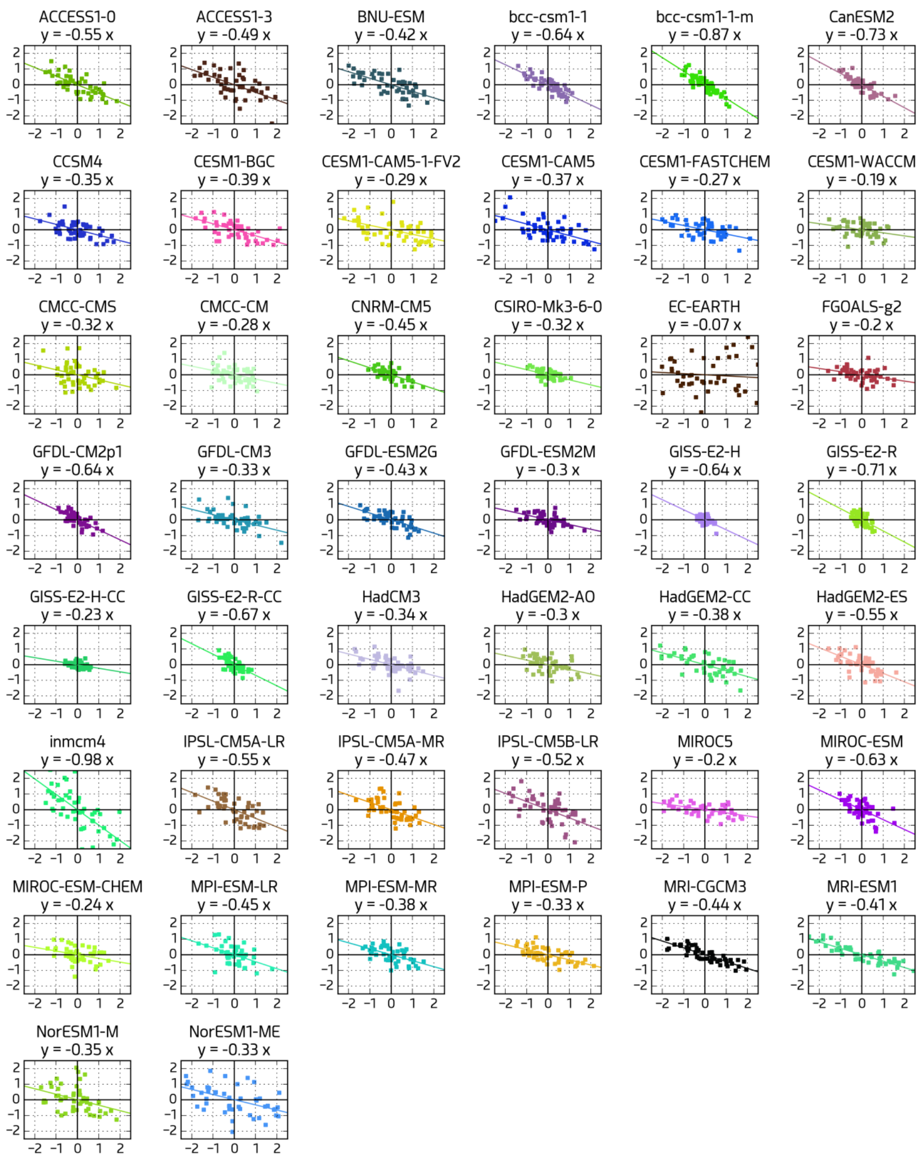
Sea ice thickness (–)

Heat conduction flux (+)

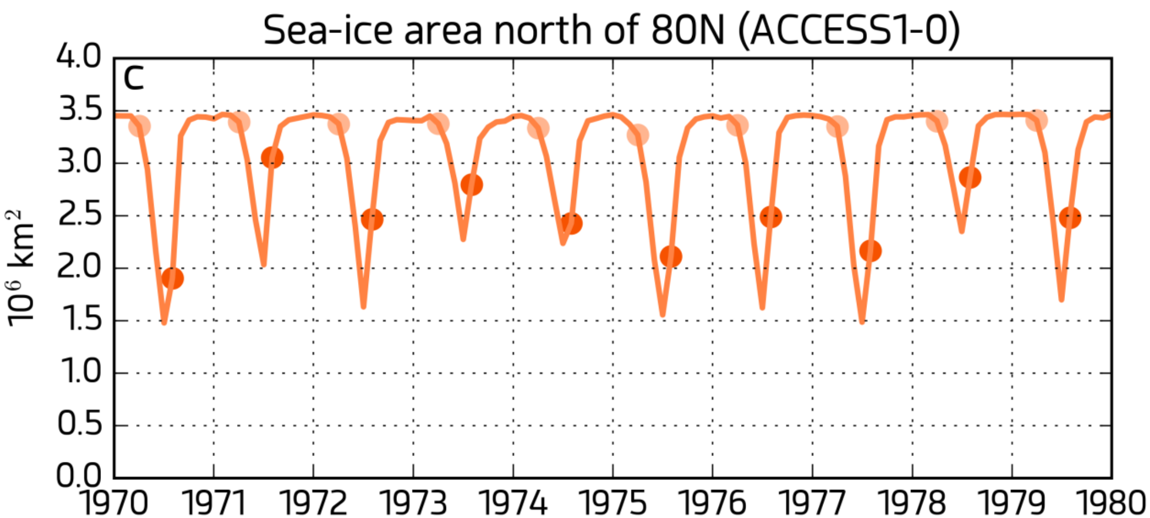
Basal ice growth (+)

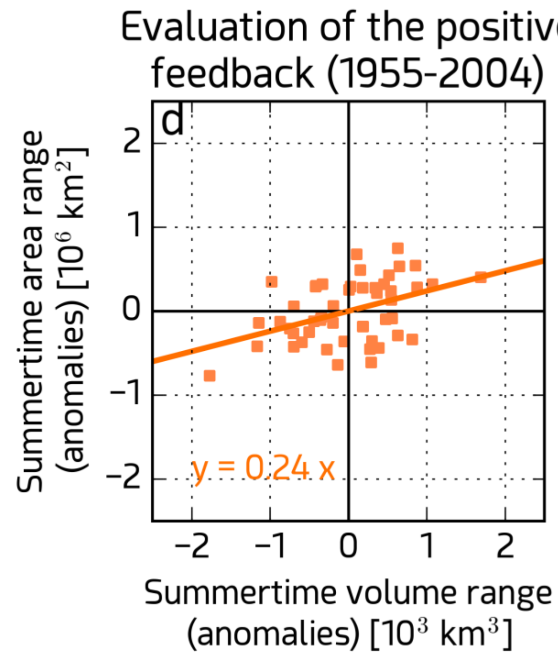
All climate models analyzed simulate the negative feedback, though differently

44 models from the CMIP5 archive



Estimating the positive feedback from model output





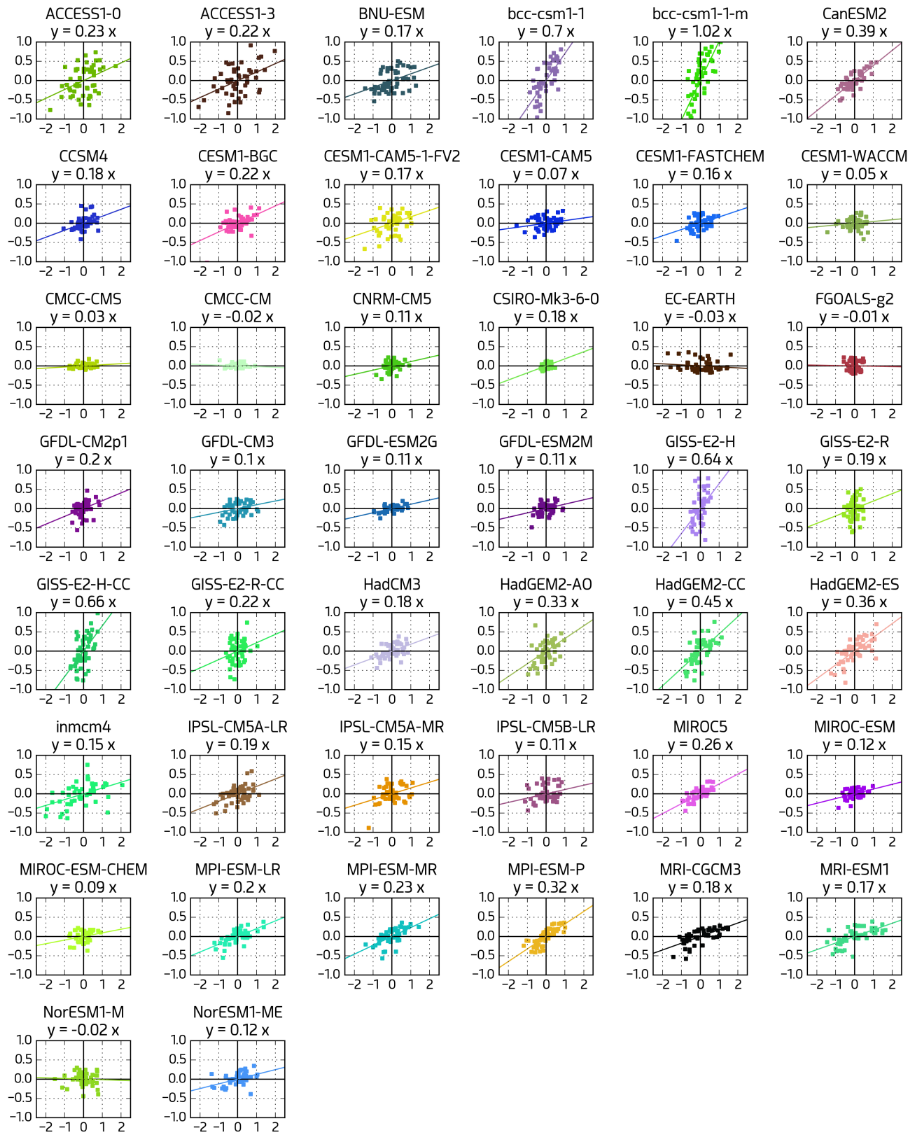
Sea ice area (–) → Surface albedo (–) → Shortwave absorption by ocean (+)

↓

Upper ocean temperature (+) → Basal sea ice melt (+) → Sea ice thickness (–) → Sea ice area (–)

All climate models analyzed simulate the positive feedback, though differently

44 models from the CMIP5 archive



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Why do climate models simulate the feedbacks differently?

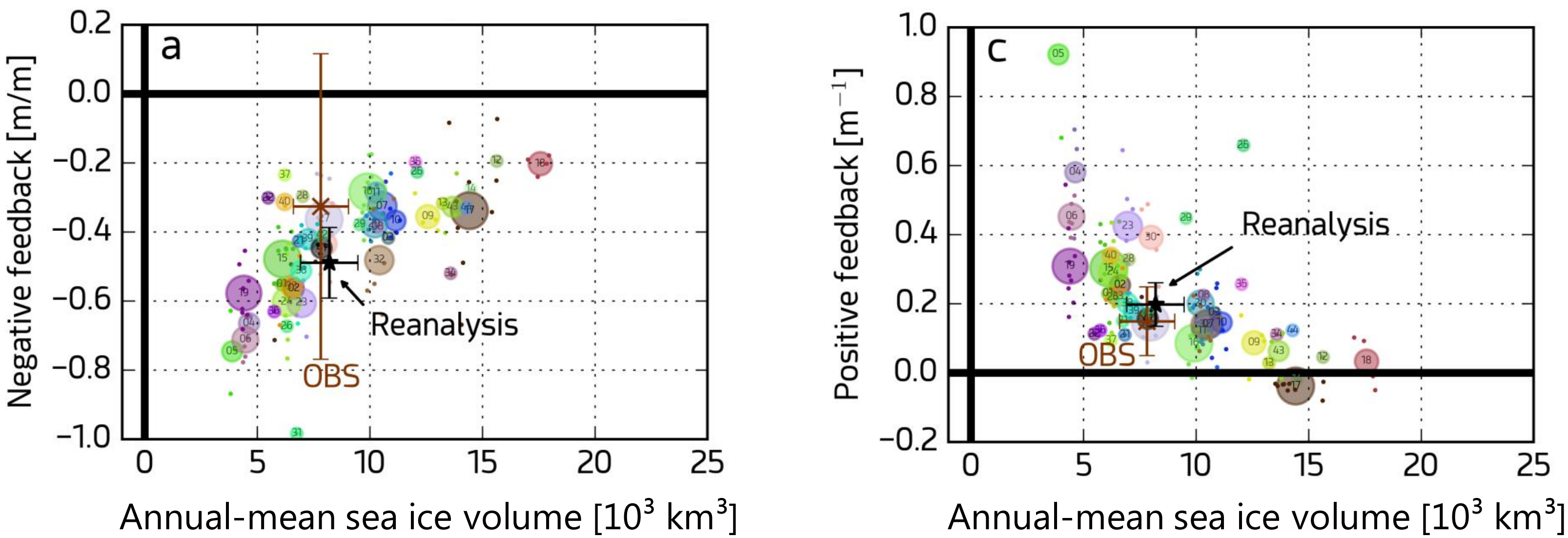
Hypothesis 1: Because their sea ice model components are different

Hypothesis 2: Because their background states are different

Hypothesis 3: Other reason

Both feedbacks are enhanced for thin ice

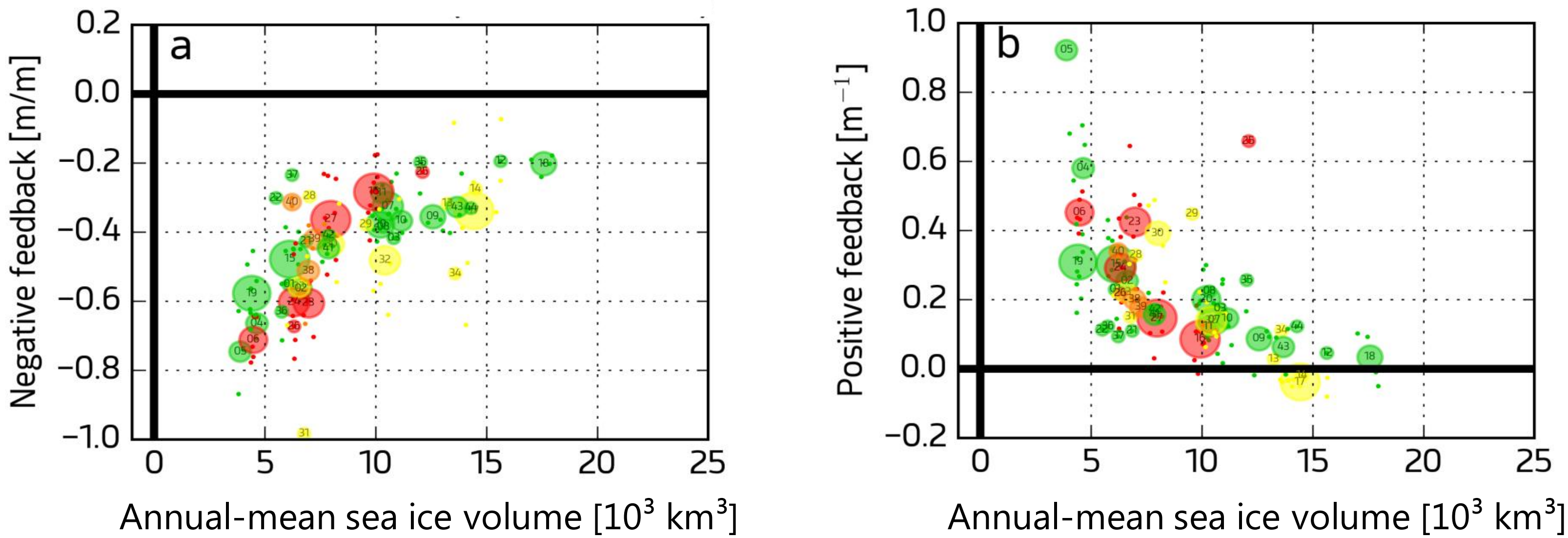
44 CMIP5 models,
1955-2004



See also Bitz and Roe, 2004; Holland et al., 2006

No link between sea ice model type and feedbacks

44 CMIP5 models,
1955-2004



The sea ice component in models

Very simple　Simple　Intermediate　Complex

Why do climate models simulate the feedbacks differently?

~~Hypothesis 1: Because their sea ice model components are different~~

Hypothesis 2: Because their background states are different

Hypothesis 3: Other reason

Four scientific questions

1 Are the two feedbacks captured by contemporary climate models?

Yes

2 Do they simulate the feedbacks differently? Why?

The background sea ice volume controls feedback strength almost exclusively

3 What is the link between the feedbacks and sea ice variability?

4 Does it matter for seasonal to decadal prediction?

Four scientific questions

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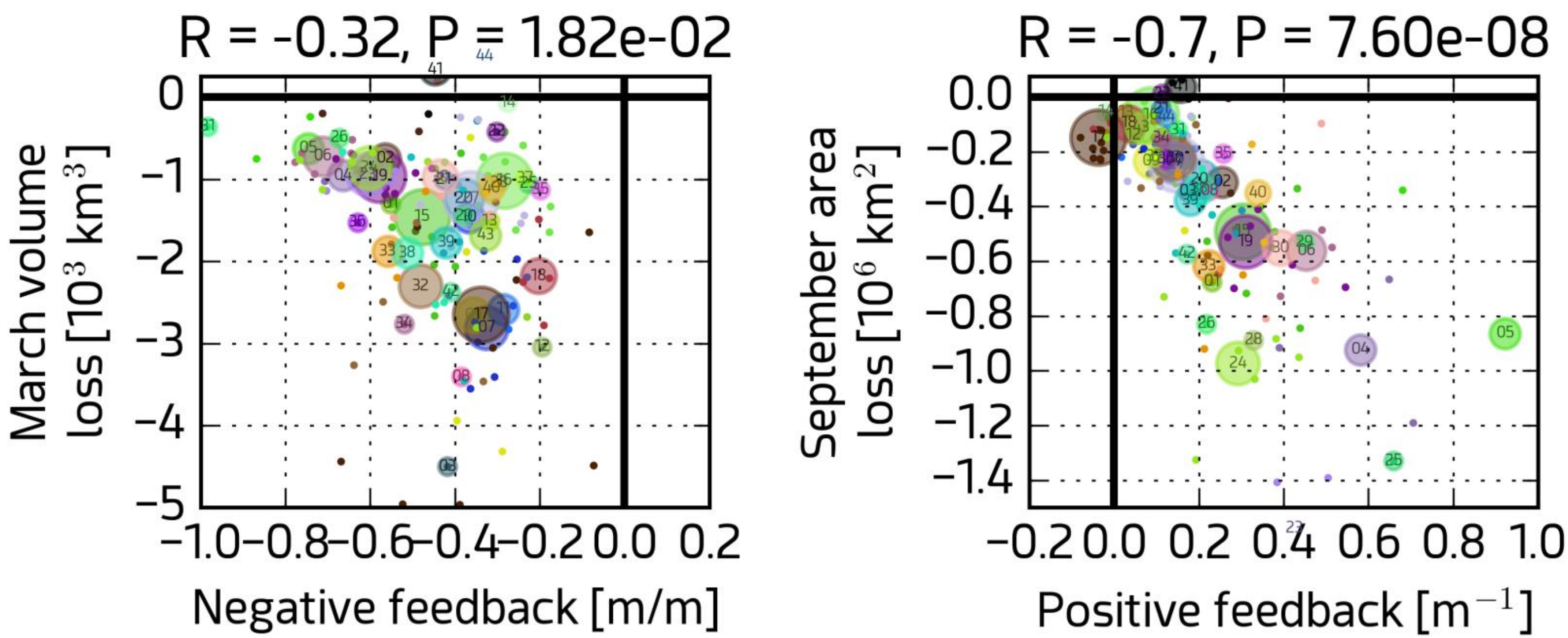
Feedback strength is a proxy for long-term sensitivity (« emergent constraint »)

44 CMIP5 models,
1955-2004



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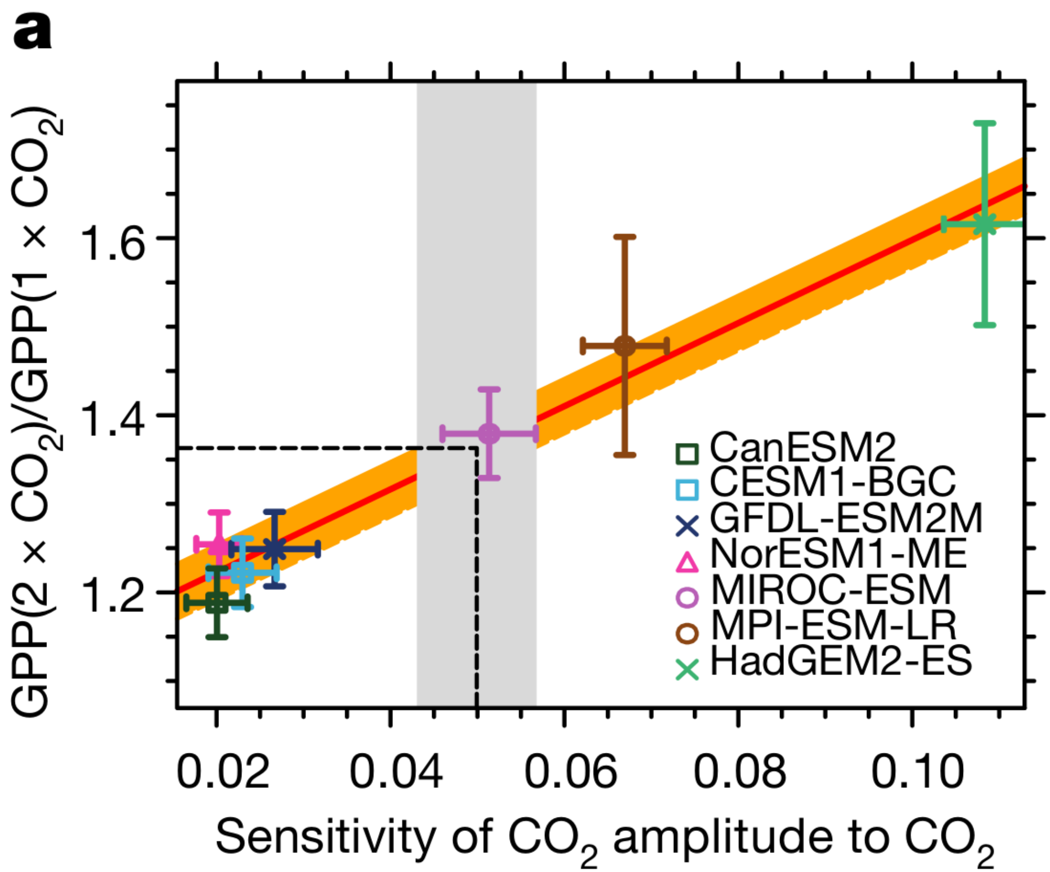

Wenzel et al., 2016

Four scientific questions

1

Are the two feedbacks captured by contemporary climate models?

Yes

2

Do they simulate the feedbacks differently? Why?

The background sea ice volume controls feedback strengths almost exclusively

3

What is the link between the feedbacks and sea ice variability?

Sea ice variability is directly connected to feedback strength. This is supported by physical understanding.

4

Does it matter for seasonal to decadal prediction?

Four scientific questions

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The background sea ice volume controls feedback strengths almost exclusively

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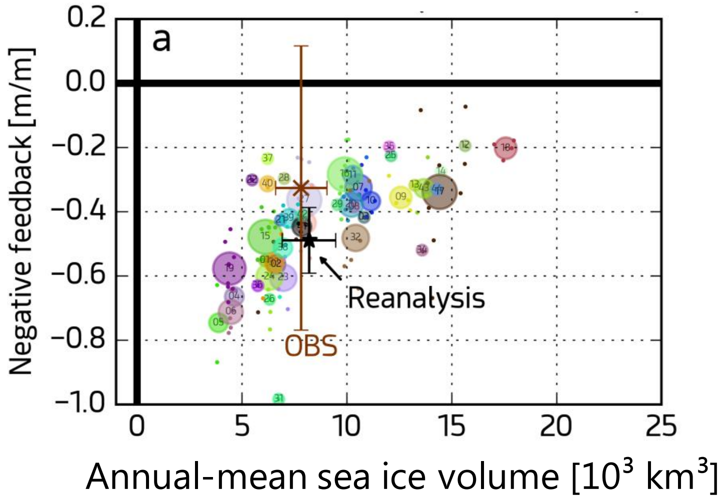
4. Does it matter for seasonal to decadal prediction?

Part 1: the mean state affects the feedback strength



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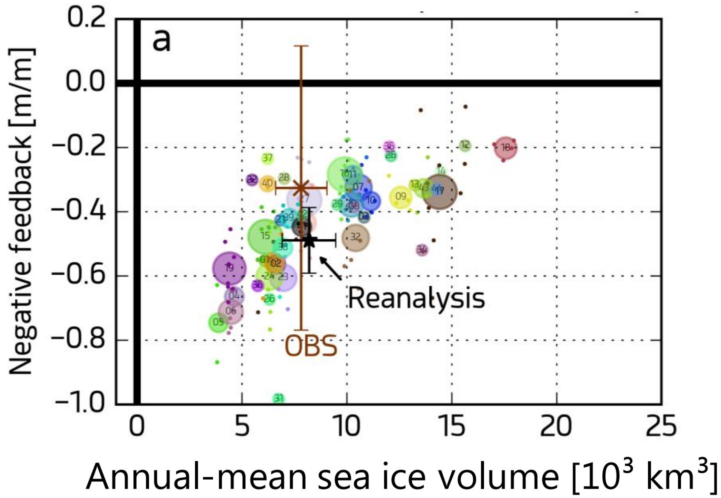
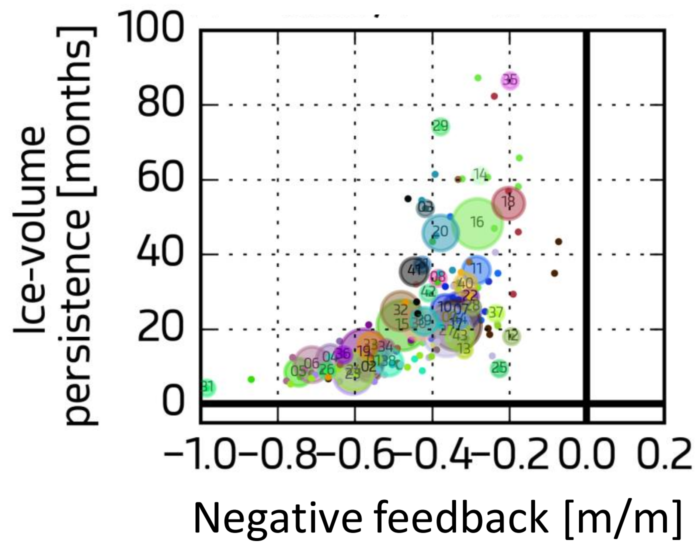


Part 2: feedback strength affects variability



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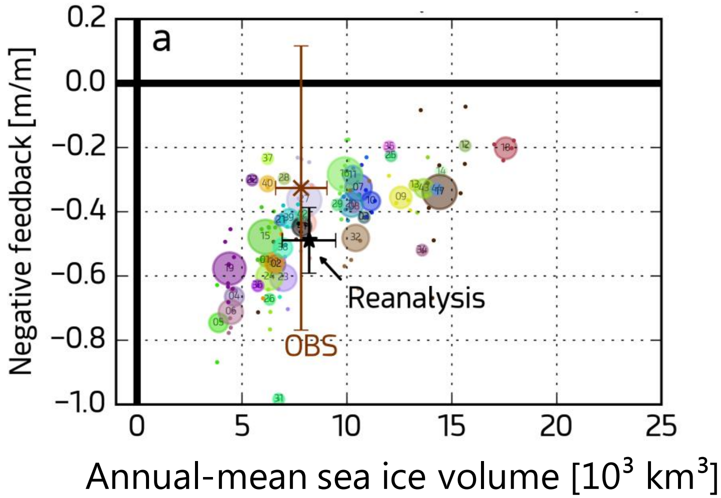
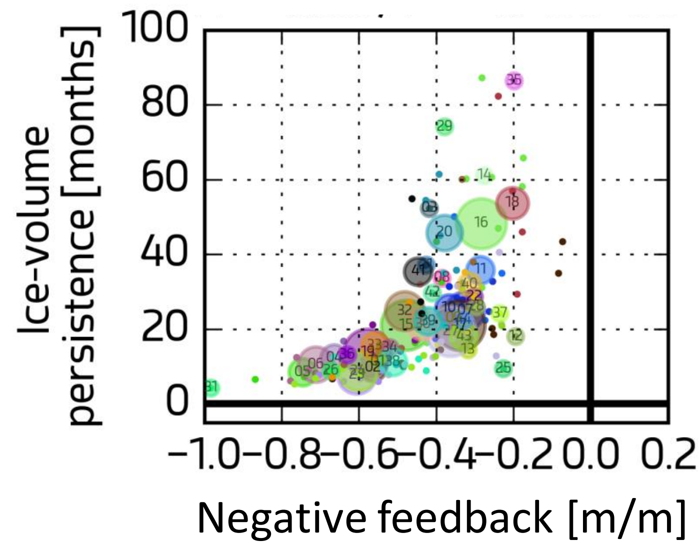
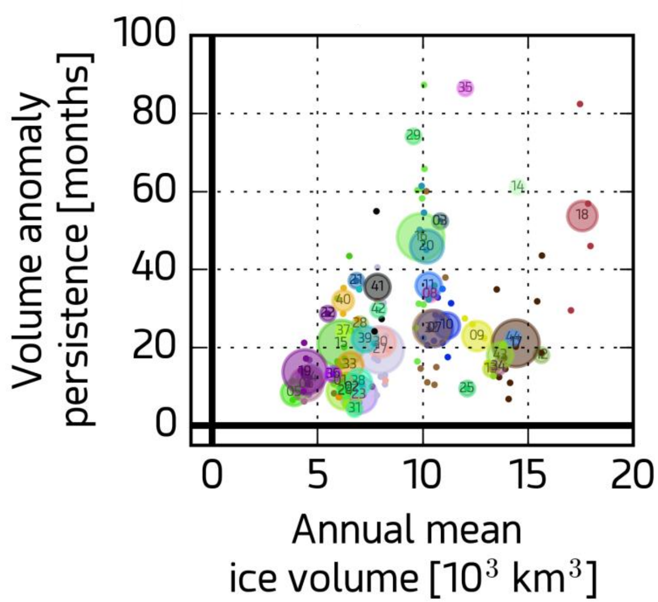


Part 2: feedback strength affects variability





Thus the mean state affects variability

Getting the right mean state is the n 1 priority!

Four scientific questions

1

Are the two feedbacks captured by contemporary climate models?

Yes

2

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The background sea ice volume controls feedback strengths almost exclusively

3

What is the link between the feedbacks and sea ice variability?

Sea ice variability is directly connected to feedback strength. This is supported by physical understanding.

4

Does it matter for seasonal to decadal prediction?

Yes. You can't investigate predictability with a biased model

Concluding remarks

The evolution of Arctic sea ice is largely, but not only, shaped by two competing thermodynamic feedbacks

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Both feedbacks are enhanced as the ice thins, so this has implications for variability and predictability

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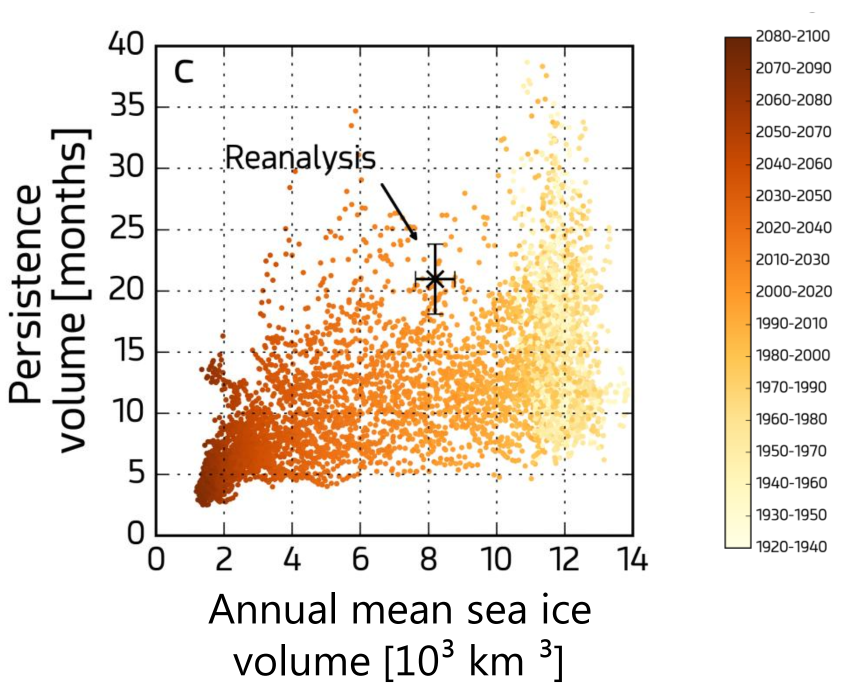

CESM model 35 members
Historical + RCP8.5
scenario

Thank you!

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References

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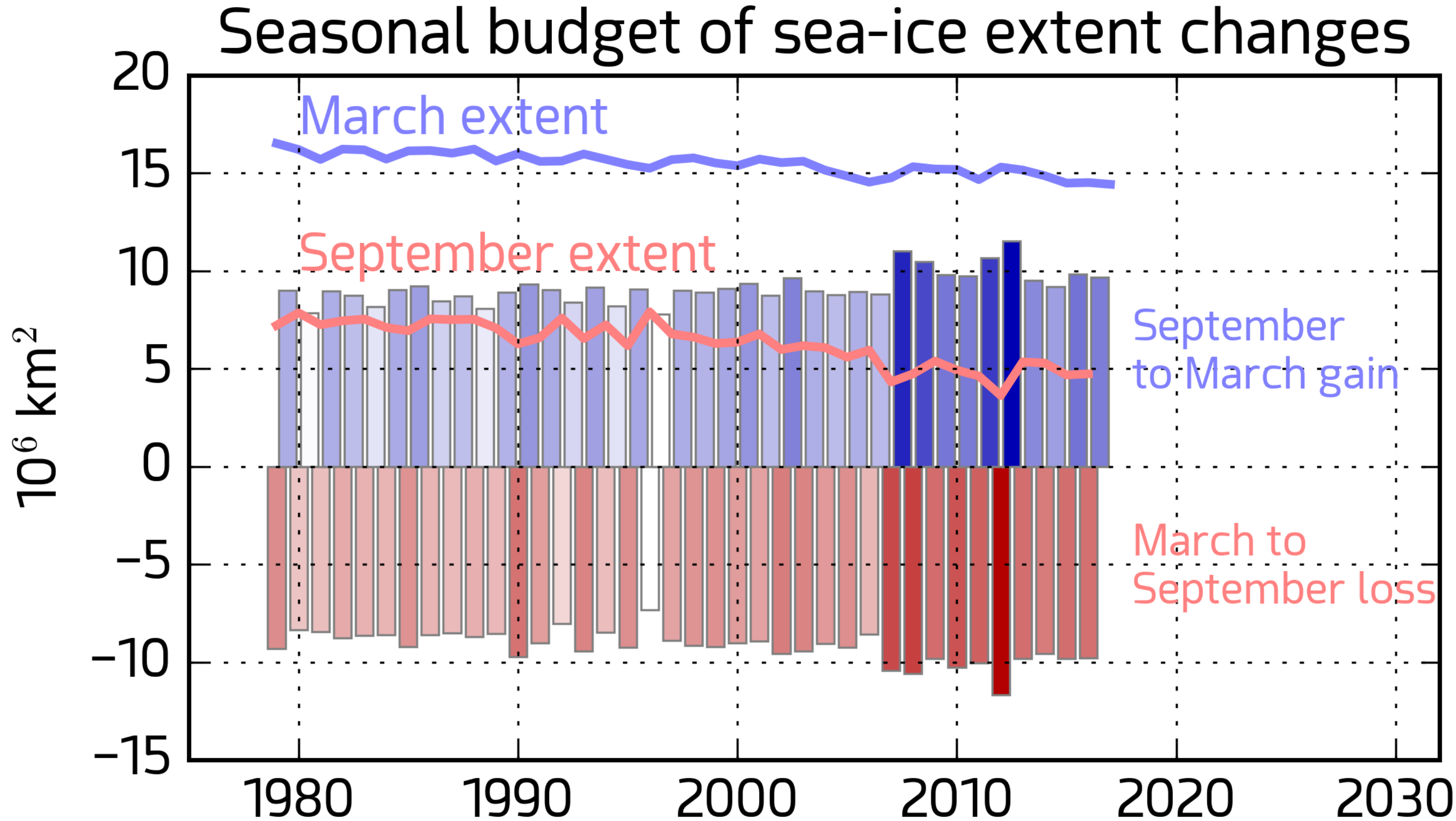
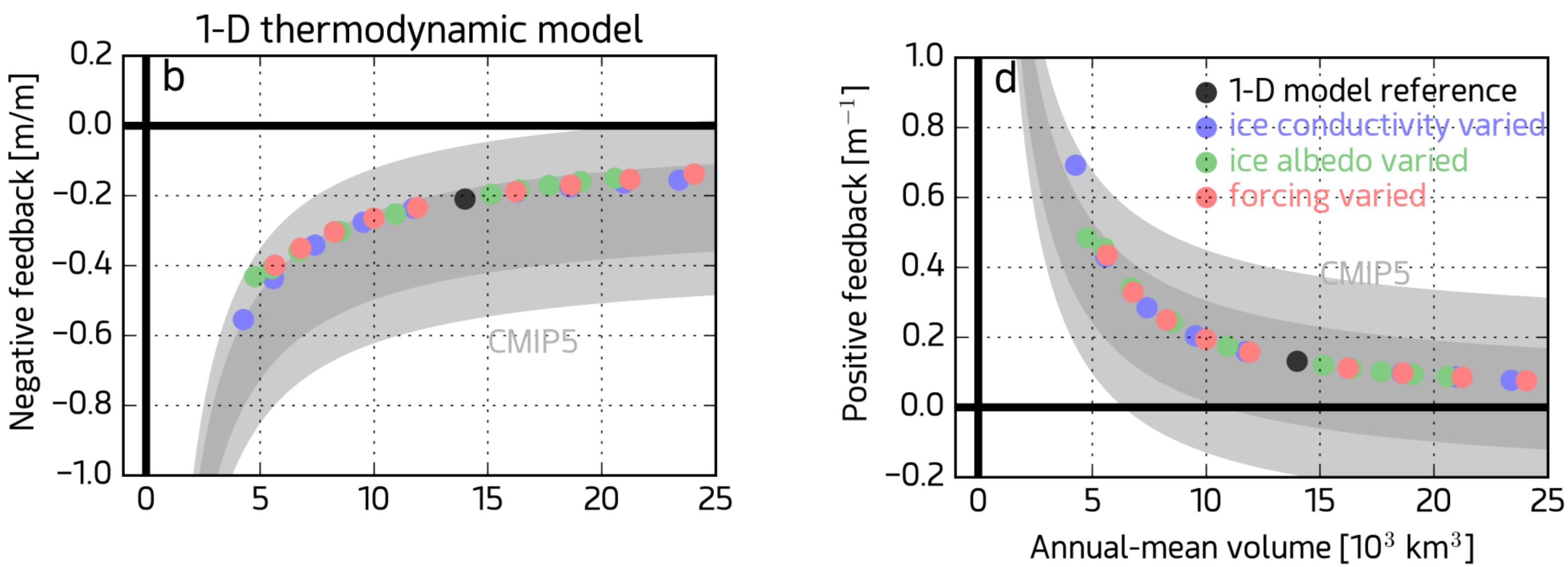
Screen, J. A. and Simmonds, I. The central role of diminishing sea ice in recent Arctic temperature amplification. *Nature* **464**, 1334-1337 (2010)

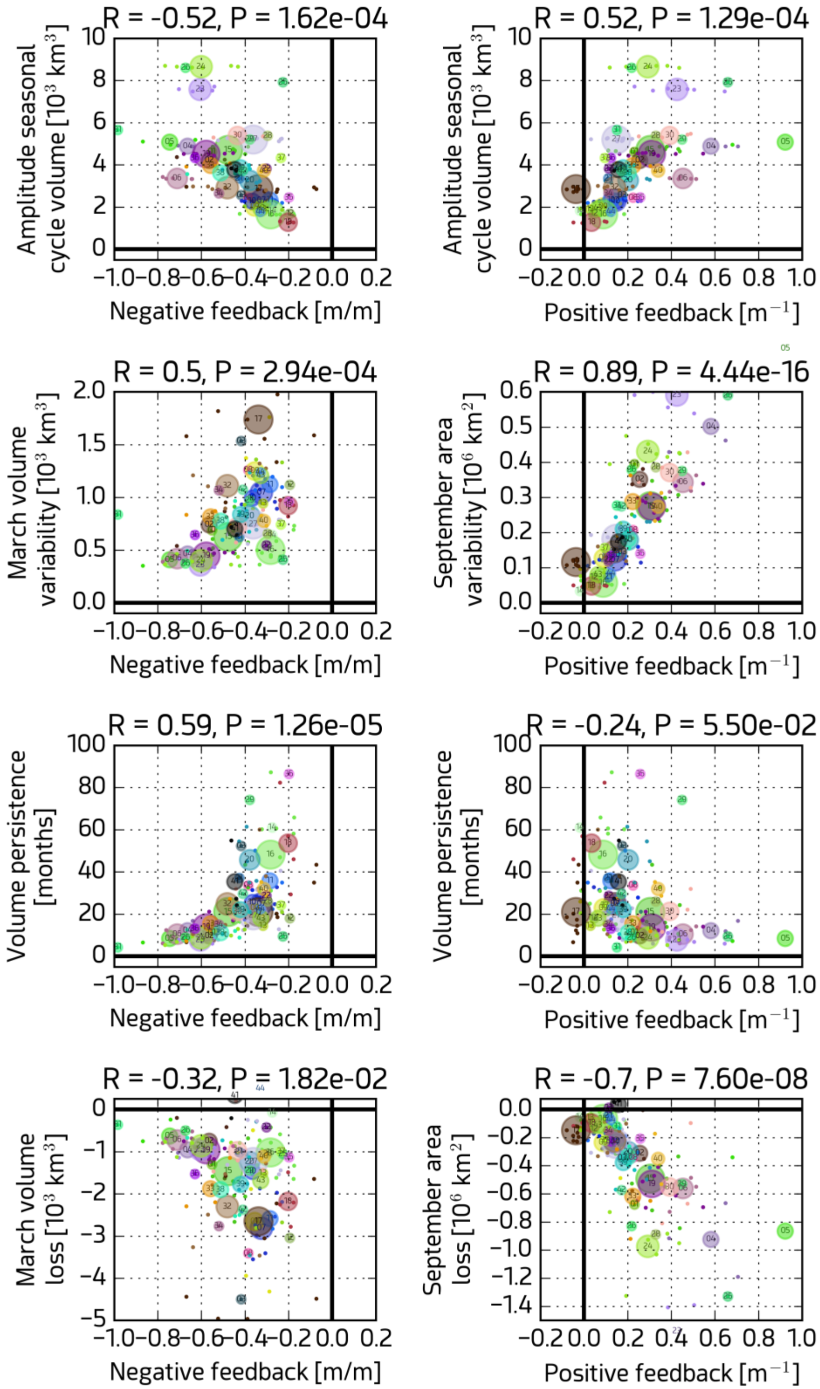
Wenzel, S., Cox, P. M., Eyring, V. and Friedlingstein, P. Projected land photosynthesis constrained by changes in the seasonal cycle of atmospheric CO2. *Nature* **538** 499-501 (2016)



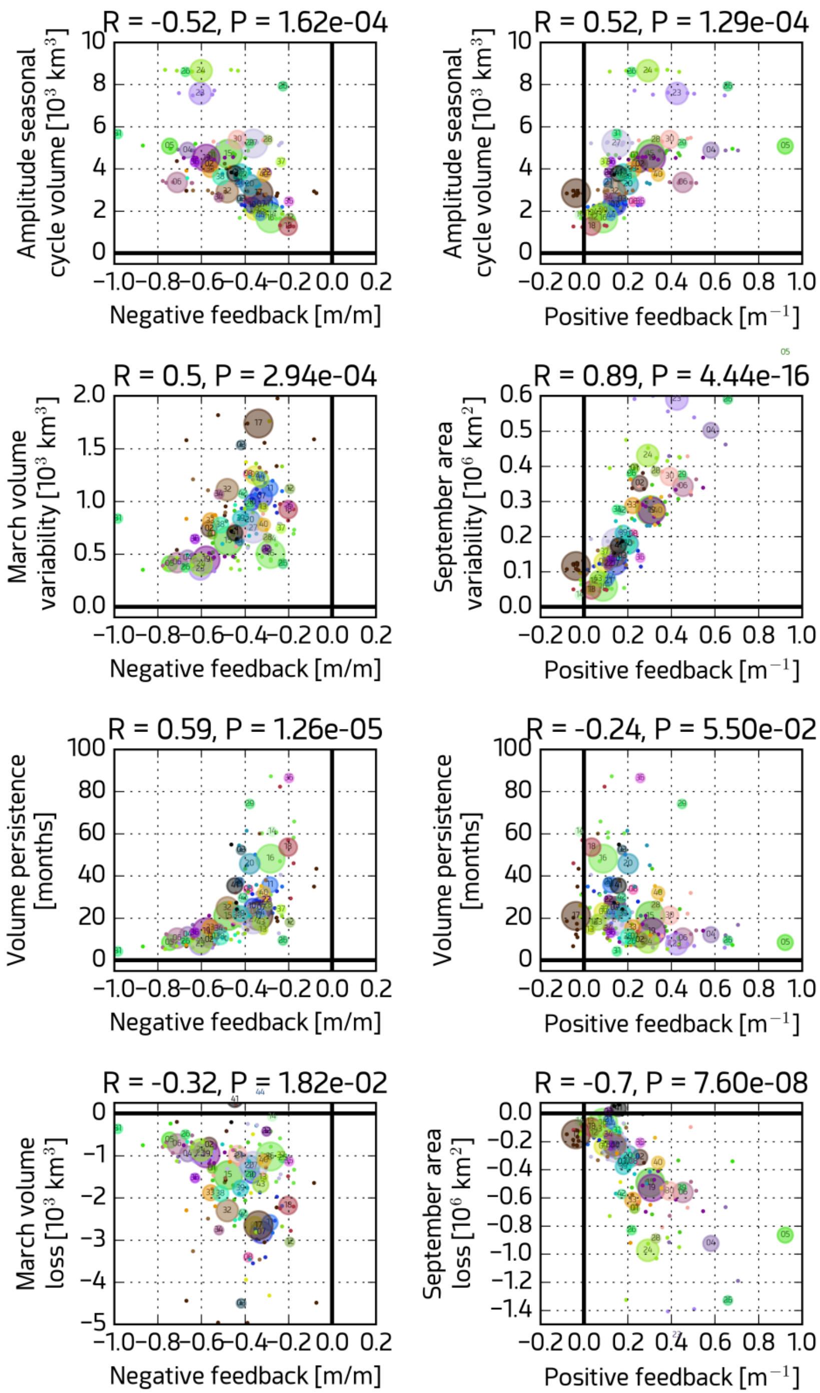
Seasonal budget of sea-ice extent changes
March extent
September extent
September
to March gain
March to
September loss
10^6 km^2
20
15
10
5
0
−5
−10
−15
1980
1990
2000
2010
2020
2030

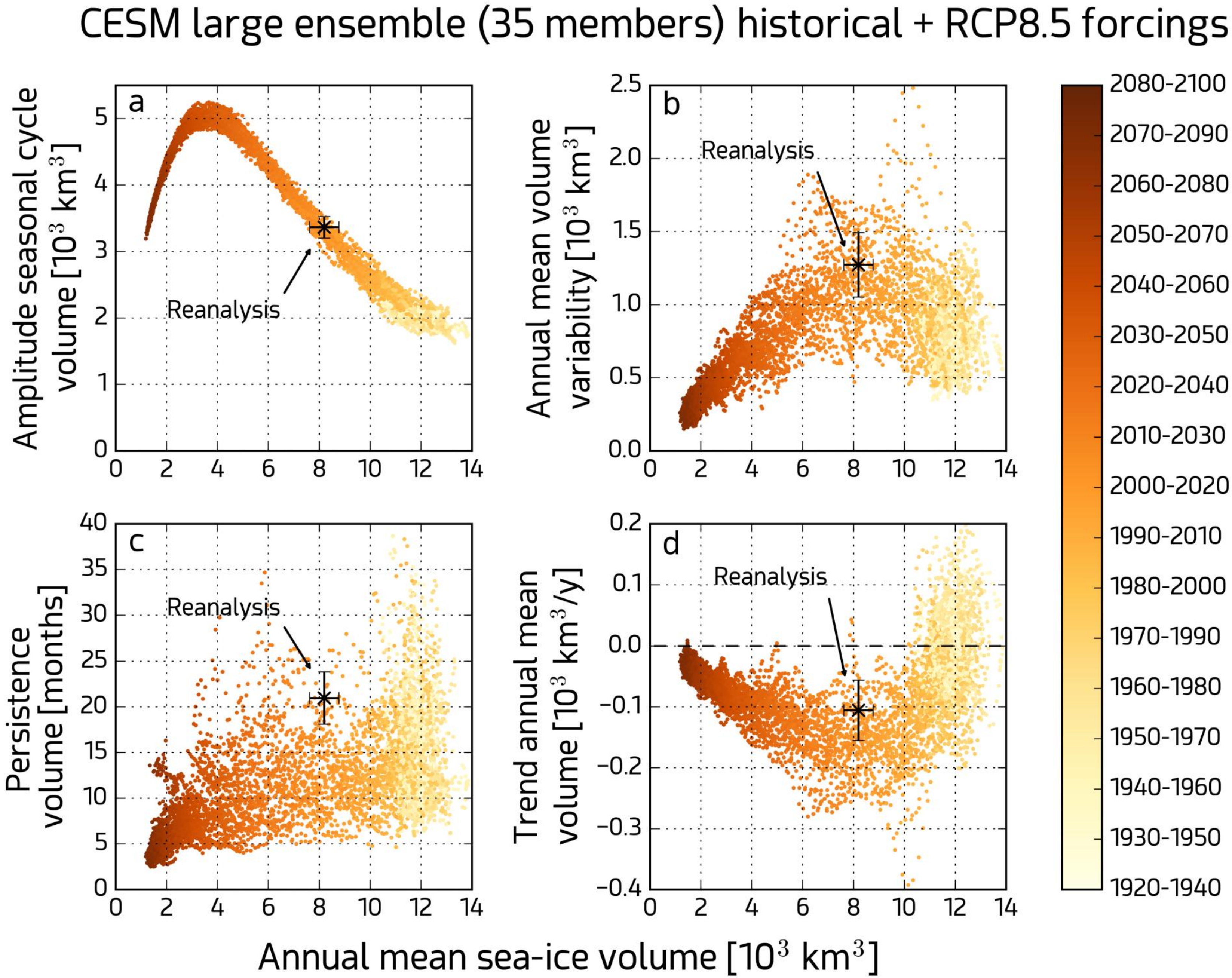
No link between sea ice model type and feedbacks





R = -0.52, P = 1.62e-04
R = 0.52, P = 1.29e-04
Amplitude seasonal cycle volume [10^3 km^3]
Negative feedback [m/m]
Positive feedback [m^-1]
R = 0.5, P = 2.94e-04
R = 0.89, P = 4.44e-16
March volume variability [10^3 km^3]
September area variability [10^6 km^2]
R = 0.59, P = 1.26e-05
R = -0.24, P = 5.50e-02
Volume persistence [months]
R = -0.32, P = 1.82e-02
R = -0.7, P = 7.60e-08
March volume loss [10^3 km^3]
September area loss [10^6 km^2]


R = -0.52, P = 1.62e-04
Amplitude seasonal cycle volume [10³ km³]
Negative feedback [m/m]
R = 0.52, P = 1.29e-04
Amplitude seasonal cycle volume [10³ km³]
Positive feedback [m⁻¹]
R = 0.5, P = 2.94e-04
March volume variability [10³ km³]
Negative feedback [m/m]
R = 0.89, P = 4.44e-16
September area variability [10⁶ km²]
Positive feedback [m⁻¹]
R = 0.59, P = 1.26e-05
Volume persistence [months]
Negative feedback [m/m]
R = -0.24, P = 5.50e-02
Volume persistence [months]
Positive feedback [m⁻¹]
R = -0.32, P = 1.82e-02
March volume loss [10³ km³]
Negative feedback [m/m]
R = -0.7, P = 7.60e-08
September area loss [10⁶ km²]
Positive feedback [m⁻¹]



CESM large ensemble (35 members) historical + RCP8.5 forcings
a
b
c
d
Reanalysis
Amplitude seasonal cycle volume [10^3 km^3]
Annual mean volume variability [10^3 km^3]
Persistence volume [months]
Trend annual mean volume [10^3 km^3/y]
Annual mean sea-ice volume [10^3 km^3]
2080-2100
2070-2090
2060-2080
2050-2070
2040-2060
2030-2050
2020-2040
2010-2030
2000-2020
1990-2010
1980-2000
1970-1990
1960-1980
1950-1970
1940-1960
1930-1950
1920-1940